Sociotechnical matters: reviewing and integrating science and technology studies with energy social science

Article (Published Version)

Energy Research & Social Science 65 (2020) 101462

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Review

Sociotechnical matters: Reviewing and integrating science and technology studies with energy social science

David J. Hess[a,*], Benjamin K. Sovacool[b]

[a] Department of Sociology, Vanderbilt University, PMB 351811, Nashville, TN 37235-1811, USA
[b] Science Policy Research Unit (SPRU), University of Sussex Business School, University of Sussex, United Kingdom

ARTICLE INFO

Keywords:
Science and technology studies
Science, technology & society
Social construction of technology
Socio-technical systems
Actor-networks
Public engagement

ABSTRACT

Theoretical frameworks associated with science and technology studies (STS) are becoming increasingly prominent in social science energy research, but what do they offer? This review provides a brief history of relevant STS concepts and frameworks and a structured analysis of how STS perspectives are appearing in energy social science research and how energy-related research is appearing in social science STS. Drawing from an initial body of 262 journal articles and books with a stratified sample of 68 published from 2009 to mid-2019, the review identifies four major groups of perspectives: (1) STS-related cultural analysis, especially the study of sociotechnical imaginaries; (2) STS-related policy analysis, such as research on the social construction of risks and standards and on the performativity of economic models; (3) STS perspectives on public participation processes, expert-public relations, and mobilized publics; and (4) the study of sociotechnical systems, including large technological systems, the politics of design, and users and actor-networks. Connections among the perspectives and the value for energy social science research are also critically discussed.

1. Introduction

The energy social science research field utilizes a wide range of conceptual frameworks from many disciplines, among them economics, innovation studies, policy studies, psychology, and sociology. Increasingly, concepts from science and technology studies (STS, also called "science, technology, and society," especially in the non-Anglophone areas of the world) are finding their way into this interdisciplinary field of inquiry. At the same time, researchers in the STS field continue to examine energy-related topics with increasing vigor.

Since at least the 1990s, energy social science work that studies the nexus of science, technology, and society has flourished, and STS researchers have accelerated their interest in energy and climate topics (with notable emphases on electricity and mobility systems in particular). However, these two streams of inquiry have largely remained epistemically, methodologically, and geographically separate. The energy studies and STS research fields involve distinct and at times disconnected epistemic communities, with different training and approaches populated by different groups of people across space and time. The situation creates ample ground for myopia and misinterpretation as much as it holds promise for interdisciplinary synthesis and effective problem-driven research. Thus, this review introduces researchers in the general energy social science research field to the nexus of research involving STS and energy social science, and it contributes to an assessment of the accomplishments and potential of this area of research.

As an interdisciplinary field, STS does not have easily demarcated boundaries. One definition, which will be understood here as the broad intellectual *space* of STS, is consistent with what students encounter in educational programs throughout the world, where the terms "Science, Technology, and Society" and "Science and Technology Studies" are often used interchangeably to refer to programs with courses taught by a wide range of faculty positioned in various disciplines. In this context, STS is any scholarly study of science and technology from the perspective of a wide range of social science and humanities fields, including historical and philosophical approaches that do not address connections with society and policy.

However, there is also a second meaning of STS. This meaning is closer to a discipline, and it will be characterized here as the STS *field* rather than STS space. In this narrower, more disciplined sense, the STS field is the study of the processes by which scientific knowledge and technological artifacts are constructed (developed, maintained, and changed) and also the study of the changes in the broader social and material worlds that occur as part of the mutual shaping, co-constitution, or coproduction of science and technology with society and the natural environment. In the Anglophone world, the term "science and technology studies" is used almost exclusively in this sense.

* Corresponding author.
E-mail address: david.j.hess@vanderbilt.edu (D.J. Hess).

https://doi.org/10.1016/j.erss.2020.101462
Received 27 August 2019; Received in revised form 26 January 2020; Accepted 30 January 2020

Researchers who have acquired knowledge of STS as a field have the capacity to see science and technology through a distinctive "socio-technical" lens. This STS vision and associated methodologies provide explanations of differences in the epistemic dimensions of science and scientific expertise (methods, theories, research priorities, etc.) that are not limited to causes based only on technical criteria such as empirical adequacy or logical consistency. Likewise, STS explains differences in technological systems and the design of material culture by going beyond causes based only on technical criteria such as functionality, cost, and efficiency. Instead, STS shows that adequate explanation of scientific and technological stasis and change, and their imbrications with society and the natural environment, require that social and cultural perspectives—understood broadly to include networks, users, firms, states, social movements, social structure (race, class, gender, sexuality, national original, etc.), global position, values, cognitive categories, institutions, and fields—are integrated into the analysis of causes and effects. STS as a field often seeks to steer a resolutely middle path between the world of epistemological relativism, where no claim to truth is better than another because everything is socially shaped, and what is generally called naïve realism, where the analytical resources for explaining science, technology, and society are reduced to technical factors.

We use the phrase "sociotechnical matters" in the title to reflect this STS field vision of social science research. In other words, we argue that the contribution of STS in energy social science is the analysis of matters that are both social and technical and that otherwise might be consigned to the black box of uninspected exogenous factors. Moreover, the thoughtful analysis of sociotechnical matters (e.g., research methods or technological design) is not trivial in fields such as energy social science; an STS-informed analytical process can lead to work that is not only more theoretically grounded but also more empirically descriptive and socially impactful in terms of influencing policy actors or other important social actors. In summary, *our* underlying vision of STS is a research field that provides the capacity to see the interconnections, mutual shaping, co-constitution, or coproduction of the technical, social, and natural.

This review begins with this basic understanding of STS as a field, and the next part of the review is used to identify historical STS perspectives that are relevant to contemporary social science research on energy. When we refer later to "STS-informed" work or "STS perspectives," we mean research largely derived from STS as a field rather than only STS as a space. The next sections describe a systematic and comprehensive method for the review of the current literature, followed by an overview of four main types of STS perspectives that are currently in use in energy social science research: imaginaries and other discursive forms; sociotechnical dimensions of policy; publics and citizen engagement; and sociotechnical systems, practices, and users.

2. STS perspectives: a brief background

2.1. The emergence of STS as an academic field

Because researchers in the interdisciplinary field of social science and energy may lack a broad understanding of STS perspectives, this subsection provides a brief background of some of the major approaches through the 1980s (See Fig. 1.) The topic is vast, and readers who wish to gain a more detailed overview of the field may take advantages of various handbooks and introductory books that describe the diverse range of problem areas and research frameworks in the field. There are several official handbooks associated with the Society for Social Studies of Science (e.g., [1]), and there are other handbooks that represent a diverse range of perspectives that are sometimes less well-represented in the official handbooks (e.g., [2–4]). Readers who are not familiar with the field may also find helpful the diverse introductory books, which in turn emphasize different aspects of the field (e.g., [5–8]). To be clear, any attempt to define central tendencies or perspectives in STS will be contested because the boundaries of the field and central ideas are themselves contested. This situation occurs with most research fields, but it may be amplified in an interdisciplinary field. Nevertheless, for the purposes of providing a background for readers who are interested in but not familiar with STS (such as energy social science researchers and STS students), and to provide a basis for the analysis of the nexus of STS and energy social science research in the results section, this section will provide an overview of some of the basic concepts that appear in the handbooks and introductions and in the STS literature as a whole.

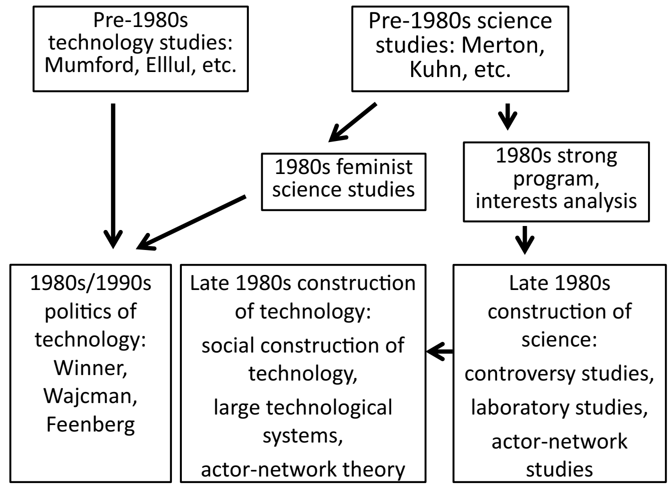

Fig. 1. Diagram of Some Influential Approaches in STS as of the 1980s. Source: Authors.

STS has long included energy among its topics of inquiry. Some of the highly influential publications of the 1980s were based on the analysis of energy systems, among them Thomas Hughes's study of electrification, which became an exemplar of research on large technological systems; Langdon Winner's analysis of nuclear energy, which became a foundation for research on the politics of design; and Brian Wynne's analysis of the response of a rural community in England to the expertise of nuclear scientists after the Chernobyl disaster, which was a foundation article in the study of expertise and publics [9–11].

Since this earlier period, the nexus of research in STS and energy social science has expanded if not prospered, and a diverse range of STS-related concepts has proven relevant for social science research on energy. Some of these concepts were developed in energy-related STS research, but many of them were developed for other areas of STS, including studies of biomedical research, information sciences, and the natural sciences. This section will review some of the central concepts in STS research in general, including studies with a focus on energy but not restricted to them.

To understand the developments in the 1980s that became known as "STS," it is helpful to have some awareness of predecessors. (See Fig. 1.) The origins of STS as we know it today have at least two separate streams. On the technology studies side, work by scholars in the mid-twentieth century developed critical analyses of the social, environmental, and political consequences of technology. Jacques Ellul, Herbert Marcuse, and Lewis Mumford were among the mid-twentieth technology scholars whose work influenced a generation of technology scholars who came of age during the 1960s, such as Andrew Feenberg and Langdon Winner [12–18]. For example, the influential work of Lewis Mumford on authoritarian versus democratic forms of material culture explored an early version of the politics of artifacts and design [16].

On the science side, a leading mid-twentieth century predecessor in Anglophone STS was Robert Merton [19]. Although his work also included some forays into what became known as the sociology of scientific knowledge, it focused mostly on the analysis of science as an institution, with attention to issues such as cumulative advantage and norms. Another important strand consisted of philosophers who built on or responded to the conventionalist tradition, such as Thomas Kuhn and Imre Lakatos [20,21]. They developed arguments that rejected simplistic empiricist accounts of how scientific knowledge changes, and their work influenced the sociology of scientific knowledge that was emerging during the 1970s.

During the 1980s, two major changes occurred: the sociology of science shifted emphasis from the analysis of institutions to the sociology of scientific knowledge, and the science and technology sides of the field became more integrated. With respect to science, most discussions for this period begin with the strong program and the idea that explanation of scientific knowledge claims and changes is not limited to technical considerations as described above [22]. The central methodological principle of the strong program is that explanations of scientific knowledge should adopt a symmetrical stance that applies the same explanatory resources to knowledge accepted today as true and as false. This approach recognizes that in the past there were controversies or disagreements about knowledge claims, and different networks of scientists interpreted the data and methods differently. One analogy is to think of the process of making knowledge in science as more like that of weighing evidence in a juridical setting with adversarial perspectives of prosecuting and defending attorneys, rather than as a process that can be resolved in a formulaic way through a single crucial experiment. Evidence does matter, but even experiments are subject to disagreements over the interpretation of results and methods, and scientists must engage in social negotiation to achieve closure for their disputes over evidence [23].

The first empirical application of this approach was “interests” analysis, and the paradigmatic case was the study of a scientific controversy over two types of statistics in early twentieth-century Britain. Donald MacKenzie argued that the definitions of the statistics and their intended use were connected to two rival networks of statistical researchers who in turn were connected with broader positions in the political field and the social structure [24,25]. However, this method faced challenges when attempting to defend the claim of causal relations from the broader societal fields of political and class conflict to the positions of rival scientific networks. For example, one network had connections to the eugenics movement and to Fabian socialism, but the causal linkages between the societal distinctions external to the scientific field and the differing positions in the controversy over statistical measures were questioned [26]. This type of linkage could be made, but it had to await the development of ethnographic and cultural methods that attended to the habitus of scientists and the cultural meanings of science to the participants in the controversy [27–29].

Instead, during the 1980s, the field developed a range of micro- and meso-level analyses of the processes of making or constructing scientific knowledge, including laboratory ethnographies and controversy studies [30]. During the 1980s sociologists also developed an analysis of the construction of boundaries, such as the boundary work that scientists undertake to maintain the integrity of the research field [31]. They also pointed to the role of boundary objects, such as shared databases, which enable researchers and publics to coordinate across diverse frameworks and goals [32]. Feminist research led by Sandra Harding developed the idea that researchers brought with them cultural categories and values, a “standpoint,” that became embedded in their concepts, methods, and agendas; and she also pointed to the potential for improved knowledge, or “strong objectivity,” that can emerge from awareness of standpoints and inclusion of diverse perspectives [33,34].

During the 1980s, some STS researchers also applied similar methods to the study of technology—essentially joining the two formerly disparate threads of technology studies and science studies. Three leading approaches at this time continue to be represented as STS perspectives in energy studies today: the analysis of large technological systems explored the phases of development of infrastructural systems such as electricity; the social construction of technology extended a framework from controversy studies to show how social negotiation could bring about the stabilization of a technological design; and actor-network analyses examined the development of heterogeneous networks of humans, organizations, laws, and technologies [35,36]. Other approaches, to some degree drawing on the critical technology studies predecessors mentioned above, explored how gender, class, political values, and other broader societal differences were embedded in the design of technology [18,37].

In summary, several concepts developed during this period remain relevant today for social science research on energy:

1 *Interpretive flexibility:* Scientific knowledge and technological design are shaped or constructed through social processes that involve negotiation over their meaning.
2 *Politics of design:* Technical distinctions can be mapped onto social or political distinctions, and these distinctions have social and political effects; that is, artifacts have politics.
3 *Sociotechnical systems:* Technological systems are heterogeneous ensembles of people, artifacts, infrastructures, research, cultural categories, norms and laws, and natural resources.
4 *Distributed agency or the agency of things (actor-networks):* In technological systems, humans can delegate to material objects the capacity to produce causes and effects within the network or sociotechnical system, but humans can also actively reconstruct or reinterpret the agency delegated to artifacts and technological systems.

Although there were other important concepts, these concepts are highlighted here because they are salient in the contemporary work on energy and social science discussed in Section 4.

2.2. Directions in STS during the 1990s and early 2000s

During the 1990s and early 2000s, the STS field underwent considerable diversification. There is no generally agreed-upon set of categories for the new developments and amplifications of existing research programs that appeared, and from the many developments, we selected five main areas. (See Table 1.) Again, these categories were selected because the methods and concepts were salient at the intersections of STS and energy social science that are explored systematically in Section 4.

The five categories are summarized here:

- During the late 1990s *anthropological and cultural approaches* in STS became more prominent, and researchers developed cultural analyses of science that focused especially on race, gender, colonialism, multiculturalism, and postcolonial/de-colonial perspectives. To varying degrees the work also brought back the topic of social structure that had received less attention after the rejection of interests analysis during the early 1980s.
- A second area that received growing attention was STS-oriented research on *policy*. Studies of expertise in the policy process drew attention to boundary work and boundary organizations, which mediate between the scientific and political fields, and to the social construction of risk and standards.
- During the 1990s and after, *actor-network theory* underwent further development and extension to general social theory and economics. Latour's study of the effects of Pasteur's science on France showed how Pasteur's capacity to shape the world required an alignment of the outside world with his laboratory so that the science could become transformed into a society-changing heterogeneous technological network [45]. This approach, when applied to economics and policy, entailed showing how economic theories can be used not just to describe markets but also to define and shape them (that is, theories have a *performativity* dimension).
- The fourth area involved increased attention to *public understanding*

Table 1
Summary of STS Perspectives Prominent in the late 1980s and 1990s.
Source: Authors.

Area of STS	Brief Description of Topics	Exemplars in the late 1980s/1990s
Cultural analysis	Symbolic meanings, cultural systems, codes, discourse, practices, gender, cultural differences, imaginaries	Haraway [28], Harding [38], Hess [39], Wajcman [40]
Policy analysis	Expertise, politics, and policy; construction of technical dimensions of policy (e.g., risk, standards)	Bowker and Star [41], Guston [42], Jasanoff [43]
Actor-network theory and performativity	Agency of things, heterogeneous networks, making of markets, calculative agencies	Callon [44], Latour [45,46], Law [47]
Public understanding and engagement	Critique of the deficit model, trust and credibility, public participation processes, social movements	Clarke [48], Epstein [49], Irwin and Wynne [50]
Sociotechnical systems	Social construction of technology, large technical systems, technological practices	Bijker et al. [35,51], Coutard [52], Hughes [53], Summerton [54]

and engagement, which to some degree overlapped with the cultural and policy turns. Research in this area began with the critique of the deficit model of the public, or the idea that public rejection of technology and expertise is due to lack of scientific knowledge and that the solution was public education and outreach.

- The fifth development of STS during the 1990s that is relevant for energy and social science is the diversification of research that is classified here under the rubric of *sociotechnical systems* and users. Work on the social construction of technology and on large technological systems continued and expanded to include governance. Another development of sociotechnical systems perspectives was increased attention to users. They play a role in the processes that lead to the stabilization of a technological design, but they also play a role in remaking technology or changing it in use [55].

In summary, the diversification and elaboration of STS perspectives provided a range of resources that appeared in social science research on energy. These approaches include the three “turns” toward culture, policy, and publics; the development of performativity analysis and extensions of actor-network perspectives; and the continued development of research on technological systems, especially the role of practices and users as both constituting and constituted by the systems. These five streams of STS perspectives are not the only ones that emerged with the diversification of the STS field during the 1990s, but they were selected here because the review process indicated their importance for research at the intersections of STS and energy social science.

With this background in mind, the review is based on the following research question: what types of STS perspectives are currently in use in research at the intersections of STS and energy social science, and what have these STS-informed research projects achieved to date?

3. Research design: multiple reviews with stratified sampling and qualitative content analysis

This review has two goals. The first, which was presented in Section 2, was to introduce energy and social science researchers to STS as a field and to STS concepts and perspectives that to date have been relevant for energy social science research. The second goal is to provide an overview and typology of perspectives in energy-related research at the nexus of STS and energy social science that uses STS perspectives. To accomplish this second goal, our study conducted a systematic review that proceeded in three stages. (See Fig. 2.) In stage 1, a data set of “candidate articles” was constructed based on searches in electronic databases that used a stratified sampling approach. In stage 2, based on a review of abstracts, titles, and keywords in the sample of candidate articles, a subset of publications was selected as “relevant articles” for review. At this stage, a preliminary classification of articles into different STS perspectives was made. In stage 3, the relevant articles were read and analyzed, and a subset of articles was selected for inclusion in Section 4 below, as described below.

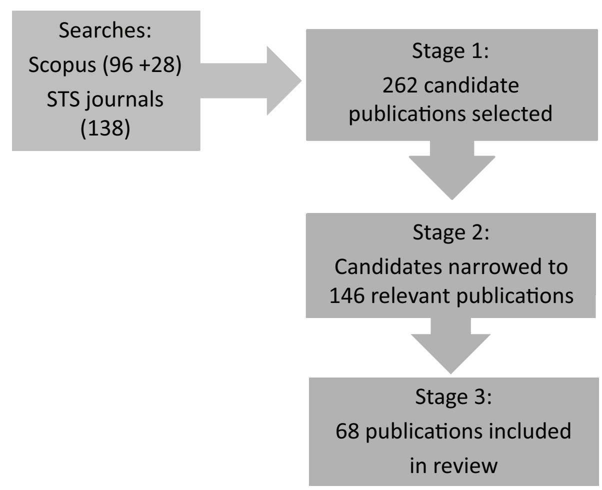

Fig. 2. Overview of systematized literature research design.
Source: Authors.

3.1. Construction of the 10-year data set

The sampling method for candidate publications was stratified into two groups of searches, one based on general searches in Scopus and the other focused on STS publications. This sampling strategy was used so that publications from a wide range of journals, including general energy-related journals and STS journals, were both included. By using a stratified sampling method with broad search terms and a wide scope of publications, the review limited bias. The construction of the data set involved two sets of searches, and the sampling strategy also identified relevant books.

The first set of searches was conducted to capture the uses of STS in the context of energy social science that was not limited to the primary STS journals. The scope of the searches was restricted to energy and did not include climate science, general environmental policy, or other related areas. The first search used “science and technology studies” combined with “energy” in Scopus for articles published during the period 2009–2019 (one decade plus the first six months of 2019). This search returned 96 candidate articles. Because the term “science, technology, and society” is also used to mean STS, a second search was conducted using that phrase instead of “science and technology studies,” again combined with “energy” and for the 2009–2010 period.

This search returned 28 results. Combining these two searches, the energy journal *Energy Research and Social Science* had the highest number of results ($N = 9$), followed by *Science and Technology Studies* ($N = 7$). An additional search was conducted in the Web of Science's Social Science Citation Index as a robustness check on the first Scopus search. This search returned 51 results, of which 50 were duplicates when the final data set was assembled. This first set of searches made it possible to see how the term "STS" is being used in the broad literature on energy rather than determining a priori what STS is and then searching for categories generated prior to the sample. These searches returned mainly articles, but in some cases, they also returned book chapters and book reviews, which were also considered in the review.

The second set of searches was conducted in STS journals based on abstracts, keywords, and titles. To capture a wide range of candidate publications, the search used only the term "energy." (The assumption was that because the articles were in STS journals, they would have some connection with an STS perspective.) Again, the search was limited to the years 2009 through mid-2019, and it focused on journals where there is social science research in the STS field, rather than on the broader STS space.

One might argue that the history and philosophy of science and technology, along with their journals, should be included in our review, but we treat them as separate fields from the STS social science research field within the broader STS space. (See the Introduction section, where we distinguish the STS space from the STS field.) The decision to demarcate the STS social science field in this way has several justifications. First, the focus of this study is on the nexus of STS and energy social science, not on the history or philosophy of energy; hence, it is reasonable to limit this part of the search to the STS journals where social science research is published. Second, research in the related fields of the history and philosophy of science and technology is often not treated as a part of the core STS community, given that it is published in its own non-STS journals (e.g., *Isis* or *Technology and Culture*), is organized with its own professional associations and meetings, and often has different graduate programs from the STS programs. Thus, there is an institutional justification for treating research in history and philosophy as separate fields that are connected to, but nonetheless distinct from, the STS field. Third, the first set of general searches in Scopus captured STS-relevant studies in both the STS space and in other related social science fields; thus, there was a mechanism for capturing the most relevant articles in non-social science STS fields. Fourth and lastly, historians and philosophers who wish to engage social science will publish in the STS journals and/or interdisciplinary energy journals such as ERSS, meaning that our systematic review captured some of their output.

Based on these demarcation criteria, the search for the STS portion of the data set included the following journals:

1 The official journals of the two leading international organizations for STS social science research: the Society for Social Studies of Science and the European Association for the Study of Science and Technology. These journals are *Engaging Science, Technology, and Society; Science, Technology, and Human Values*; and *Science and Technology Studies*.
2 The other leading social science journals in the STS field with the highest impact factors where social science STS research is published: *Public Understanding of Science, Science as Culture*, and *Social Studies of Science*.
3 To ensure international diversity outside the North Atlantic region, two leading publications that include STS social science research in Asia and Latin America (*East Asian Science, Technology, and Society*; and *Tapuya: Latin American Science, Technology, and Society*).
4 To check if the policy-oriented literature had new and different frameworks not captured by the general Scopus search, *Science and Public Policy*. (There were no differences in types of frameworks, but most of the policy papers were not relevant because they used frameworks from fields other than STS.)

Searches in the STS journals were conducted in Scopus except for *Engaging Science, Technology, and Society*, which was not indexed in Scopus and was examined through the web site. Additional searches were conducted inside the journal publisher's search engine using the full text of articles to check on the results, and these searches indicated that the searches in Scopus were capturing the most relevant publications. This set of searches resulted in 138 candidate publications. When combined with the first set of searches, a total of 262 publications were selected for the first phase of reviewing.

In summary, the goal was to gain a broad, inclusive sample of research at the intersections of STS and energy social science. The review is not an attempt to include all publications related to STS and energy, an effort that would exceed the confines of a single review article.

3.2. Selection of articles

Stage 2 of the analysis began after the completion of the data set ended. In stage 2, the analysis shifted from the "candidate" publications as defined above (Stage 1) to the subset of "relevant publications" based on reading the abstracts, keywords, and titles of the candidate articles. (See Table 2.) The main criterion for moving a publication to the second stage was a significant engagement with one or more STS concepts. Many articles mentioned an STS concept or conceptual framework but did so only in passing, and the main framework was from another field. The range of "non-STS" perspectives is large, and sometimes there are overlaps. Non-STS perspectives in the general energy social science field that appeared in the data set were mostly from the following fields: policy studies, behavioral and social psychology, education, and general sociology. Research on sociotechnical transitions has some overlaps with STS, especially at the early stages of its development [56–58]. Furthermore, within transition studies the multilevel perspective synthesized STS and innovation studies to explain how sociotechnical systems change [59,60]. However, because this area of research developed into its own field and came to focus on the problem of

Table 2
Summary of Searches and Stages of Review.
Source: Authors.

Searches (2009–2019)	Stage 1: Candidate publications from main searches	Stage 2: Subset of relevant publications	Stage 3: Included in review
STS Journals: "energy" for each journal	138	85	38
Scopus. "Science and technology studies" and "energy"	96	58 (non-duplicates)	28
Scopus. "Science, technology, and society" and "energy"	28	3 (non-duplicates)	2
Total	262	146	68

sustainability transitions, it was not included as an STS perspective. In another group of articles that was not included, the research was descriptive and without significant theoretical engagement (mostly history). For edited book volumes, only the introductory essay was reviewed. This second stage of the analysis resulted in 146 articles deemed relevant enough for more careful consideration.

Stage 3 involved a selection from the relevant articles for the final set of articles that were included in the review. The lead author reviewed the introduction, literature review, and conclusion of each article for possible inclusion in the final review (Section 4 below). Articles were included in the final review if they met one or more of the following criteria: significant engagement with the STS literature with an energy focus, a novel perspective on the literature, and the use of empirical material to support a novel perspective on the literature. Articles were not included in the final review if they made passing reference to the STS literature or concepts; if their topical focus was only tangentially related to energy; if they used an STS-related concept to orient a largely descriptive project, but the description was not used to develop or elaborate the concept; or if they were programmatic or editorial statements. This process of selection from the relevant articles resulted in 68 publications, which formed the basis of the review for Section 4 with some additions from bibliographic references. The number of included articles is consistent with that of other reviews in the energy studies field, which have N's between 42 and 100 (e.g., [61–63]).Again, the goal was not to create a comprehensive catalog of all uses of STS-related concepts in all research on energy but instead to develop a more analytical overview of the different types of perspectives that are appearing at the intersections of STS and energy social science.

3.3. Analytic strategy

At Stage 2, the lead author coded the publications, with each one categorized as representing one or more STS perspectives. The method for coding the articles was similar to grounded theory, but as corrected by constructivist critiques that recognize the theory-ladenness of observations [30,64]. To be more specific, the coding did not assume that the categories would come only from the "data." Rather, coding began with "emic" theoretical categories associated with STS as they appear in the publications, that is, terms that the authors used such as "counter-expertise," "large technological systems," or "technoscientific imaginaries." But coding also drew on the definitions of STS and the use of core concepts in the STS literature, including discussions in handbooks and overviews, as discussed in Section 2. For example, categories such as "windows of opportunity" or "technological innovation systems" were recognized as belonging to the policy literature and innovation literature respectively, and a publication that was mainly framed in terms of such concepts was excluded from the review unless it also used more recognizably STS perspectives. An iterative process of three rounds of coding akin to grounded theory led to a final set of categories that became the main structure of the review. Some articles were coded as having more than one STS-related perspective. The coding process resulted in several categories with only 1 or 2 articles and one category with many articles (public engagement). Categories with a small number of articles (too small to form a section of the review) were grouped into larger categories. (See Table 3).

This iterative process resulted in four groups of categories of STS perspectives. First, all culturally related approaches were placed in one group. Work on imaginaries was main the type of cultural perspective, but the group "cultural approaches" also included a smaller number of other studies that used similar concepts such as fantasies and expectations. Second, policy-related approaches were grouped together into two subgroups: studies of risk and standards informed by the social construction perspective, and actor-network and performativity perspectives that focused on policy issues. (Actor-network perspectives were also included in the study of users.) Third, the public engagement group was large and was divided into two subgroups: public participation and public mobilization. Fourth, a general category of sociotechnical systems and users was developed. The first subgroup included general work that made reference to sociotechnical systems or perspectives, and the second subgroup was research on sociotechnical systems with respect to users and practices. A few remaining articles were classified into a residual category that was not used; these articles included work in the history and rhetoric of energy research.

If more than one perspective was identified, the count for each perspective in Table 3 was increased. Thus, the number of perspectives in Table 3 is slightly greater than the number of relevant articles. Percentages do not necessarily sum to 100 because of whole-number rounding. These four areas were also used to select and group the historical overview of different areas of STS perspectives from 1990 to the present in Section 2.

A few clarifications may be helpful. First, the term "coproduction" appeared in some articles, but it was used to refer to a general orientation that involved attention to both technical and social orders [65,66]. Because the term was used in combination with some other perspective, such as the social construction of standards or imaginaries, it was not included in Table 2 as a separate category. Second, the public participation literature is large, but much of it does not include active engagement with STS perspectives and was not included. Third, as indicated above, actor-network approaches appeared with various topical applications and were discussed in the section on policy and the section on users and practices.

Finally, the category "sociotechnical systems" was used to cover a range of general analyses including the social construction of technology, large technological systems, actor-network approaches to users in sociotechnical systems, and the politics of design. This group also included research on sustainability transitions (such as the multilevel perspective); however, those articles were only included if they had significant engagement with an STS perspective in addition to a transition studies framework such as the multilevel perspective or technological innovation systems.

4. Results: discourse, policy, publics, and sociotechnical systems in STS energy scholarship

As described above, this section categorizes STS perspectives at the intersections of energy-related STS research and STS-influenced energy social science research in four main groups: (1) imaginaries and other cultural approaches, (2) STS and policy (risk, standards, and performativity), (3) public engagement and mobilized publics, and (4) sociotechnical systems and users. Table 4 offers an overview of these four dimensions of scholarship as well as examples of concepts and perspectives within these four broad categories (Again, note that actor-network perspectives appear in thematic areas other than policy, including users and practices.).

4.1. Imaginaries and other cultural approaches

By the 1990s, STS research had developed to include various studies of the cultural assumptions and meanings of science and technology, including feminist and postcolonial studies of technology [28,29,38,40,67]. This work also introduced into STS the longstanding idea in anthropology that symbolic and material orders were co-constituted or co-constructed [39]. A wide range of cultural methods was developed, including the analysis of cultural systems, codes, habitus, discourse, practices, and logics. Of particular relevance for energy studies is work on technoscientific imaginaries, which are collective assumptions and representations that facilitate, envision, or contest a sociotechnical order [68,69].

Current research at the intersections of STS and energy social science uses a variety of terms to describe collective representations of sociotechnical futures, including anticipation, visions, fantasies, expectations, and imaginaries [70–74]. In this data set, the term

Table 3
Frequencies of STS Perspectives in Relevant Articles.
Source: Authors.

Topics	STS Searches (85 articles)	Scopus Searches (61 articles)	Both Searches (146 articles)
Group 1: Cultural approaches	12 (14%)	11 (15%)	23 (14%)
Group 2A: Policy—construction of risk and standards	5 (6%)	4 (6%)	9 (6%)
Group 2B: Policy—actor-network and performativity	3 (3%)	7 (10%)	10 (6%)
Group 3A: Public engagement—participation	26 (30%)	11 (15%)	37 (23%)
Group 3B: Public engagement—mobilized publics	11(13%)	6 (8%)	17 (11%)
Group 4A: Sociotechnical systems—general	17 (19%)	16 (22%)	33 (21%)
Group 4B: Sociotechnical systems—users (includes actor-network theory)	9 (10%)	12 (17%)	21 (13%)
Other: history, rhetoric, scientific knowledge	5 (6%)	5 (7%)	10 (6%)
Total perspectives coded	88	72	160

"imaginaries" was used most frequently. Jasanoff and Kim originally defined sociotechnical imaginaries as "collectively imagined forms of social life and social order reflected in the design and fulfillment of nation-specific and/or technological projects" [75] (p. 120). They described different features of sociotechnical imaginaries to facilitate comparison, including the framing of risks, policy, controversies, and civic epistemologies. The latter term refers to the forms of public knowledge-making and argumentation [76]. Longhurst and Chilvers added that imaginaries or sociotechnical visions can be analyzed into four constituent units that can be used to guide comparison: normative framings and meanings, epistemic orders, sociomaterial collectives, and forms of governance and social organization [77].

One approach to imaginaries has been to develop comparative analyses of national imaginaries associated with official government policies related to science and technology such as nuclear energy development [75,78]. Research on national imaginaries tends to examine them historically, and Foucauldian approaches have appeared [79]. This approach to imaginaries can also show how they contribute to the stabilization of an existing sociotechnical regime. For example, in a study of the nationalist, "high modernist" imaginary in Taiwan, Yang and colleagues showed how narratives involving short-term electricity scarcity and limited operating reserves helped to maintain the electricity regime and to prevent the integration of alternatives that included renewable energy [80].

One commentary on the use of imaginaries suggested several methodological cautions especially for the study of single national imaginaries [81]. Because the state is always divided (by parties, spatial scale, branches of government, etc.), it is capable of generating multiple imaginaries that can be in conflict with each other. Moreover, mobilized publics in the form of civil society organizations, communities, emerging industries, and social movements also develop diverse alternative imaginaries of sociotechnical futures, some of which may be aligned with official state imaginaries and some of which may not. Hence, there is potential to develop analyses of competing and contested imaginaries. This approach resists treating imaginaries only as semiotic codes or cultural systems and instead embeds them in social fields that connect collective representations with the strategies of collective and individual actors.

Table 4
Prominent science and technology studies (STS) themes in energy social science.
Source: Authors.

Dimension	Examples	Description and benefit for energy scholarship
Cultural	Imaginaries, fantasies, expectations	Reveals the contested ways in which sociotechnical and material futures are imagined and strategically deployed
Policy	Risk, uncertainty, ignorance	Shows divergence between expert and public understandings of risk, as well as how different actors understand risks
	Standards	Unpacks coproduction of standards and governance in development and implementation
	Performativity, actor-network	Demonstrates the capacity of scientific models to rearrange sociotechnical orders and their failures to do so
Publics	Construction of publics and experts	Illustrates how participation makes publics, examines the expert-public relationship
	Alternative forms of engagement	Analyzes experimental forms of participation built on the critique of shortcomings of existing models
	Mobilized publics, counter-expertise	Examines the ways in which movements and counter-movements mobilize with respect to sociotechnical issues and how they work with scientists
Sociotechnical systems	Large technical systems	Describes the emergence and path dependence of very large infrastructural and socio-material systems
	Politics of design	Connects pervasive structural inequality with the design of artifacts, infrastructures, and governance
	Users and practices	Explores the complex dynamics by which users and sociotechnical systems are co-constituted, including in heterogeneous networks

Consistent with these methodological cautions and revisions of definition, the literature on imaginaries has shifted attention from official, state imaginaries to those produced by non-state actors. In the introduction to an edited volume on imaginaries, Jasanoff recognized that imaginaries "can be articulated and propagated by other organized groups, such as corporations, social movements, and professional societies" [71] (p. 4). For example, Kim developed an analysis of imaginaries associated with social movements that contested the official imaginaries in South Korea [82]. Likewise, studies of contested development in the global South explored the official imaginaries oriented toward development, electrification, and industrialization goals, but they also examined alternative imaginaries more appropriate to low-income residents of rural communities [83,84]. With a similar approach, an analysis of contested imaginaries in the uranium and coal extraction industries showed how workers drew attention to the value of blue-collar work and community economic well-being [85]. Although these imaginaries did not circulate in the national policy fields, they nevertheless contested the national imaginaries at the local level.

Zilliox and Smith further developed the study of imaginaries by showing how different social groups can articulate competing imaginaries within a specified political field [86]. Focusing on the politics of natural-gas fracturing technologies in the U.S. State of Colorado, they described the imaginaries of three mobilized publics, two of which opposed and one of which supported the local deployment of natural-gas fracturing technologies, and the official imaginary of the local government, which drew on scientific expertise to narrow the terms of public engagement while also constructing fracking activists as unruly. Thus, the authors developed a dynamic perspective on multiple imaginaries that linked them to actors in a contested field.

Some researchers have also examined imaginaries or related concepts from the perspective of the strategies of actors [87,88]. With respect to wind energy in South Korea, a successful approach to gaining community acceptance involved developing a carefully framed imaginary of a beneficial future that was combined with the practical demand for local ownership of energy generation [89]. In another analysis, multiple and convergent future-oriented "fantasies" were used to defend a future that includes small, modular nuclear reactors while also ignoring public concern with risk [73]. Moreover, by breaking down the fantasies about modular nuclear energy into constituent units, the fantasies helped to unite diverse constituencies. Levidow and Papaioannou also drew attention to the strategic use and implications of expectations, or representations of future technological situations that guide technological and economic activities, including public and private investment [72]. When actors receive investments and approval, expectations can become obligations of delivery. In a study of UK bioenergy policy, they showed that expectations for future bioenergy technologies enabled industry actors to gain support but also contributed to the lock-in of the fossil-fuel based energy regime.

In summary, work on imaginaries and related concepts has shifted away from the analysis of the stable, official sociotechnical imaginary of a national government to fields of contested imaginaries and the strategic use of imaginaries or similar symbolic constructions. When the analysis of imaginaries is connected with the strategic action of actors in a social field, a convergence emerges between the study of sociotechnical imaginaries and research in energy studies on framing strategies and discourse coalitions [90,91]. Nevertheless, the sociotechnical perspective does help to bring to attention a slightly different aspect of the study of symbolic representations in energy social science research. Whereas work on frames and storylines may tend to make reference to broad social values such as fairness, consumer benefit, and democratic process, work in the STS tradition also shows how symbolic representations can focus on the future of technological systems, thus bringing a more material perspective to this mode of analysis in energy research. This work also reveals design conflicts over technological systems and connects with the "politics of design" perspective discussed below.

4.2. Sociotechnical dimensions of policy

This section and Section 4.3 are the two more policy-focused sections. This section has two subsections that review policy-oriented research where STS perspectives are particularly salient in energy social science. The first subsection covers the social construction of risks and standards, that is, how their definitions, design, and implementation mutually constitute political organizations and processes. The second subsection covers actor-network and performativity perspectives on policy.

4.2.1. Risk and standards

As indicated in Section 2, during the 1990s, STS researchers became interested in the social construction of risk (a quantifiable unknown) and uncertainty (a known unknown but less predictable and measurable) [92,93]. Work on risk also included differences between expert and public understandings (e.g., [50]). STS researchers also turned their attention to the construction, maintenance, contestation, and interpretive flexibility of standards, understood as rules that establish uniformities across space and time [41,94].

In contemporary research involving STS perspectives on risk and energy, one example in this data set is Fujigaki's work on nuclear energy in Japan [95]. This work showed how a government report on nuclear energy in Japan predicted that with power loss, a meltdown could occur, and the predicted sequence of events and timing was a close match to the events at Fukushima. However, because the event received a low probability rating, the experts' conceptualization of risk did not lead the government to require contingency plans, a decision that also saved money in the short term. The estimate of low risk was due partly to the lack of integration of nuclear engineering risk assessment with risk-related research on tsunamis and earthquakes. But the conceptualization of risk also failed to take into account the severe societal implications of a rare event; hence, it underestimated the magnitude of harm. In this analysis, Fujigaki used Beck's distinction between scientific rationality (expert knowledge) and social rationality (public perspectives on what needs to be protected) to discuss not only how expert and public understandings of risk are different but also how they have different policy implications for disaster prevention policy [92,95].

The gap between expert and public understandings of risk occurs in both the predictive construction of future risk and in the communication of risk after a disaster. In the wake of the Fukushima disaster in Japan, the public wanted "impartial, nonpartisan, and broad information," whereas expert professionals provided "decisive action guidelines and limited, absolute information" [95] (p. 17). The gap led to a breakdown in trust and credibility, and the attempts by government officials to reassure residents rang hollow. The official constructions of risk failed to connect with the everyday risks that people encountered, especially in exposed areas. A gap emerged between the scientific risk assessments, which scientists admitted were incomplete, and public understandings of uncertainty and indeterminacy.

Other work in energy studies has examined public perceptions of risk associated with ongoing exposure to risk from pollution, especially for controversies over extractive technologies such as hydraulic fracturing. Some work uses survey data to examine the causes of variation in public perceptions of risk [96,97]. This research is not particularly connected with STS perspectives, but it has shown how political ideology, geographical location, and other social factors affect public understandings of risk. Research more connected with STS perspectives has identified the absences of knowledge that would enable the public to assess risk and uncertainties. For example, the politically generated and strategic use of ignorance is caused by government policies and industry practices that restrict disclosure, and in some cases communities and civil society organizations have mobilized to redefine disclosure rules and policies, which in turn affect the capacity to define and assess risk [98].

Another line of risk-related research involves attempts to improve risk governance by integrating societal perspectives with technical analyses of risk [99]. For example, one approach recognized the complexity of governing the large technological systems associated with energy and proposed polycentric governance mechanisms that bridge scale and engage multiple stakeholders [100]. Potentially these improvements could include the integration of citizen science into risk governance processes. For example, the development of citizen science helped to bridge some of the gap between official and public perceptions of risk in Fukushima [101]. However, for women citizen scientists in Fukushima, the use of citizen science also tended to preclude activism, which was viewed as a more masculine form of engagement with the problem [102].

The development of technological standards can be one response to risk, and thus the study of risk and standards overlaps to some degree. Although perceptions of risk can be addressed in many ways, and standards can also emerge from many causes, there is an intersection when governments and private-sector organizations such as trade associations develop standards and guidelines to address perceived risk along with other goals. There were only a few studies in the data set that took standards as the main topic of analysis and that adopted an STS perspective.

One general approach to research on standards examines the processes of social negotiation involved in establishing standards. For example, one study drew attention to the coproduction of standards and administrative structures in which they were embedded [103]. In this case, civil society organizations mobilized to contest standard-setting processes in Europe for biofuels, and they produced new knowledge to support their claims. In response, the European Union modified the process for setting standards by including changes in the epistemic jurisdiction of organizations that were involved in the standard-setting process. For example, the changes included outsourcing some of the more controversial decision points, a decision that simultaneously shaped the standards themselves and their governance processes. Another approach to the social negotiation of standards drew attention to the process of scientization in standard-setting, that is, the limitation of policy discussions to a small range of technical issues [104]. By focusing biofuels standards on greenhouse-gas accounting, the standards were constructed to preclude other issues that civil society organizations had raised.

The obverse side of the analysis of standards involves the constructive processes that occur in implementation. In a comparative analysis across countries, Kester and colleagues showed substantial variation in the adoption of standards, including strategic selectivity in China, aggressive compliance in Europe, and fragmented adoption in the U.S. [105]. At the microlevel, users and professionals also modify and selectively implement standards [106]. From this perspective, standards are scripts that actors perform that are subject to interpretive flexibility and domestication. For example, studies of the implementation of building standards or codes found that actors engage in practices that are aligned with the code, but they also modify it, appropriate it to keep in place existing relationships, or reconfigure their existing relations with each other and technology [106,107].

In summary, although energy policy research makes reference to the concepts of risk and standards, an STS perspective helps to take these concepts out of the black box of official definitions. Instead, it shows how risk and standards are developed through processes of social negotiation that create formal and translocal definitions to guide policy and practices. In other words, it brings attention to the processes by which risk and standards are made, maintained, legitimated, and changed, and how the processes coincide with changes in organizational and social arrangements. The research also shows how the processes tend to marginalize the goals of less powerful social groups, especially those of civil society and mobilized publics. Moreover, the research also draws attention to practices that reinterpret risk based on citizen science or that reshape standards through implementation. Thus, the construction of risk and standards occurs both in the phase of establishing them and in the implementation processes.

4.2.2. Actor-networks, performativity and policy

Actor-network theory and performativity theory are relevant to multiple areas of energy-related research, and some work that uses actor-network theory is included in Section 4.4 as well. One application of this approach at the intersections of STS and energy social science has been in policy-relevant work. Some of the studies in the data set adopted an actor-network perspective on policy issues by viewing energy policy implementation as a heterogeneous network of human and non-human actors. For example, a study of the U.K. policy that guided the development of an experimental wave-energy facility argued that policy was not an external context to the energy project; instead, both the policy system and the energy projects were mutually constituted or coconstructed heterogeneous networks [108]. Likewise, a study of the "rearrangement" of the heterogeneous network of solar manufacturing that was imported into Taiwan showed how government "translators" were as central to the network's development as were engineers and technicians [109]. These approaches contribute to sociotechnical thinking by viewing policy and technological systems as interconnected and mutually constituted networks rather than as a relationship between an exogenous rule-setting organization and a technological system or industry.

Performativity theory extends the actor-network perspective by including the models and concepts of economics in the heterogeneous systems. Work on performativity, economics, and policy draws attention to the idea that economics does not just describe the world as a social science but also can be used to configure social practices and technological systems in its image by establishing frames for calculative agencies that correspond with economic models [44,110]. Another way of describing this perspective is that it argues that economics "not only describes but also participates in performing and hence actually changing the economy and the society more widely" [111] (p. 6). The performative power of economics lies in the embedding of calculative practices in assemblages or networks. In line with the actor-network studies just described, the performativity of economics is co-constructed with government programs and powers. This process establishes frames that define and circumscribe action so that the systems operate in ways consistent with economic models.

Like the critiques of the neoclassical rational-actor models by economic sociologists and institutional theorists, research from this perspective recognizes how the frames of economic models and calculative practices encounter limits in practice. Because economic frames and calculative practices are not capable of covering the complexity of the world that they describe and translate, and because some actors contest attempts to define a sociotechnical network or assemblage according to a specified set of rationalized practices, "overflowing" results [112]. To some degree, this problem is recognized in economic theory as the problem of externalities, but performativity theory views externalities as one example of a broader category.

Strategies for managing the overflowing of economic frames include reframing and modifications in the material dimensions of the assemblage. For example, in a study of regulatory decisions for energy infrastructure in the UK, overflowing was managed through the use of "statements of common ground," which included participation from environmental organizations and contributed to the capacity of regulatory agencies to make better decisions [113]. In a study of feed-in tariffs in France, overflowing occurred as the problem of unpredicted growth in distributed energy, and it was addressed by a series of policy changes and successive shifts in the assemblages [114].

The concept of overflowing enables a performativity framework to include political conflict. For example, a study of a proposal for siting a wind farm in France showed that although the planning process involved extensive community participation and offered clear economic benefits to the area, the carefully constructed frames overflowed because the townspeople came to view the farm as conflicting with their economic development goal of developing the area as a site for historic tourism [115]. But the economic framing of political conflict can also limit and channel (or scientize) political conflict. In another case, the frames of economics channeled political conflict over energy policy in Chile by forcing the mobilized publics to “economize” their equity claims by translating them into the dominant economic frames [116]. Likewise, in Finland, political conflict over a proposal to shift a district heating source from oil to wood biomass also took place within the scientized frames of economics, but different groups invoked and supported different types of calculative practices [117]. In a study of a capacity market for electricity in the U.S. (a requirement for load-serving entities to purchase access to reserve capacity), Breslau agreed that the construction of the market involved a set of calculative practices consistent with the performativity perspective on economic models [118]. However, when the generation companies and system operator gained federal government approval for a change in the demand curve that provided an economic transfer of payments from consumers to generation companies, the consumer-facing companies mounted an opposition campaign, but they did so within the frame of the constructed demand curve and market. In all of these cases, the performativity aspects of economics were less to create calculative agents and practices and more to create a frame that limited or scientized conflict.

In summary, although economic research is certainly an important part of energy social science, STS perspectives shift attention from merely applying economic theory to the description and explanation of research problems. Instead, the performativity perspective, like the analysis of risk in the previous section, draws attention to processes of sociotechnical construction. In this case, the sociotechnical perspective shows how economics can also be a set of models that come to life through calculative agencies in heterogeneous assemblages that frame decision-making and, at a second order, create processes through which political conflict is channeled and translated. One might argue that the frameworks of policy studies and economic sociology already provide adequate ways of explaining similar dimensions of policy conflict (e.g., in research informed by the concepts of neoliberalism and scientization), but some researchers have found that the frameworks of actor-network theory and performativity provide additional insights. Specifically, the actor-network and performativity perspectives contribute to awareness of how policies that implement economic models and practices also construct a particular type of agency and, to an extent, become self-fulfilling. This agency is created through the co-construction of government policy networks and those of sociotechnical systems or assemblages. Moreover, the performativity approach also draws attention to the problem that, like the sorcerer's apprentice who conjures the brooms to life in order to haul the water, the frames of the world that the models conjure into being tend to “overflow” with the unexpected.

4.3. Public and citizen engagement

During the 1990s, STS researchers developed critical analyses of expert constructions of lay knowledge and the deficit model of the public understanding of science. They examined the inverse problem of how the public constructs trust in experts, and they suggested the potential for more robust knowledge and policy when non-expert perspectives are included in technological design and disaster remediation [50]. Subsequent research on publics became connected with the burgeoning practices of public participation, and a research field developed on the effectiveness and shortcomings of these processes [119,120]. Another approach to science, technology, and publics focused on mobilized publics, which range from civil society advocacy organizations and community groups to social movements. These mobilizations contributed to the development of new epistemic forms such as popular epidemiology, participatory research, and citizen science; identified areas of undone science; articulated “counter-public” visions of the public good in contrast with official visions; recruited scientists and other professionals to provide counter-expertise; and contributed to the development of new forms of technology [48,49,121–124]. This section reviews the policy-relevant research on publics with two subsections: public participation and mobilized publics.

4.3.1. Public participation

STS perspectives on public participation focus on the processes by which different aspects of participation are defined or constructed, including the policy issues, the agents or persons invited to participate, the procedures, and the public [125]. Although the growth of participation processes can be viewed favorably as a mechanism for enhancing democratic engagement in the governance of technology, the processes often fall short of promises and can serve to legitimate decisions made elsewhere. Much of the STS-related research on public participation has analyzed the assumptions of the standard models of participation and the implications for participation processes, but some of this work has also examined how publics are constructed through these processes.

STS-oriented research in this area is heavily influenced by work during the 1990s on the shortcomings of the deficit model of the public understanding of science, which refers to the way that experts and policymakers view the public as lacking in scientific knowledge [50]. Other shortcomings that the literature identified include the decide-announce-defend model of communication to the public, the location of engagement downstream in the planning process after decisions have been made, the limited scope of who is invited to public consultation exercises and what can be discussed, and the generally weak connections between outcomes of consultations and policy decisions [126–128]. Researchers also found that even where improvements are made, they often are superficial. For example, a study of wind farm consultation processes in Australia found that although there were improvements to the consultation processes in response to criticisms, the processes still precluded significant community involvement and empowerment [129].

In addition to contributing to the literature on the shortcomings of participation processes, STS-informed research also shows how government-managed participation processes constitute or construct the public rather than discover a pre-existing public [119]. One example of how this perspective translates into empirical research is the study of the varieties of publics that are constituted through participation processes. For example, in a cross-sectional study based on 238 cases of public participation in the UK, Chilvers and colleagues found that the most widespread understanding of the public was as a “mass to be consulted,” which appeared in 119 of the cases, followed by the public as consumers in 82 of the cases [130] (p. 204). However, they also found some evidence of constructions of the public as “active, creative, innovative, resourceful, and knowledgeable,” including mobilized publics [130] (p. 205). Another study adopted a historical approach to official constructions of the public and used the concept of imaginaries to explore how government representations of the public have changed over time in the UK [131].

Related research has examined how industrial actors construct the public. For example, a study of renewable energy companies and their engagement strategies for siting found that the primary understanding of the public was as uninformed but concerned, a view that led to engagement strategies based on exhibitions rather than public meetings [127]. A study of British utilities found that because the utilities tend to view the regulatory agency as the representative of the public, they do not see a need to have other, more direct forms of engagement or the need to redefine customers in broader terms [128]. Regulatory requirements that restrict how utilities can engage the customer also facilitate the narrowing of the public to the customer. Researchers have noted that the concept of “energy citizenship” can provide an alternative way for government and industry to conceptualize the public that departs from framings of the public as consumers or as self-interested Not-In-My-Backyard (NIMBY) opponents [132,133].

A third approach to the construction of the public is work on energy researchers' definitions of the public and corresponding engagement strategies. For example, a study of bioenergy experts was the basis for a comprehensive grid of expert conceptualizations of imagined publics based on axes of active/passive publics and accepting/resisting publics [134]. Studies of energy scientists have also shown how they have a range of positions with respect to how to engage the public, from non-engagement and outsourcing engagement to upstream engagement and participatory knowledge production [135] [136]. Thus, this area of public participation research explores how different definitions of the public are associated with different forms of expert engagement.

The public engagement literature has also examined critically the techniques or technologies of public participation, and it has developed experiments with alternative designs [119]. A few examples that involve energy provide a sense of the potential and variety. One approach is to think about the point where the engagement is located in the cycle of technology development. There is some hope that anticipatory or upstream engagement may be more effective because it provides public input before a new technology has become stabilized or before a government or industry planning process has solidified [128,137]. Another approach is distributed participation, in which a dialog is organized by a central group but run online and in multiple sites by a network of organizations [138]. This approach can increase the scale of participation to include thousands of people from geographically dispersed areas and thus open up the public perspectives to emergent properties that result in political engagement and opinion change. A third approach is the landscape symposium, which enables residents to discuss affective dimensions of their valuation of local landscapes in a more open forum than a formally controlled consultation process [139]. This approach can reveal differences in preferences across communities, such as for the acceptable scale of wind farms and the relationship between acceptability and current land use. A fourth approach is to have social scientists embedded in government positions, where they can provide a “challenge function” that helps to bring more sophisticated understandings of the public into government consultation programs [140].

In summary, STS perspectives in the public participation literature tend to depart from the broader literature on public participation by examining how participatory and consultative processes construct publics rather than merely represent them. Just as the previous sections show how an STS perspective problematizes risk and economic models by examining processes of coconstruction with sociomaterial orders, STS perspectives on publics question underlying assumptions about definitions of participation, publics, and democracy. These perspectives examine how different types of publics are constructed through different participation processes, and they have developed some concrete exemplars of alternative designs for participation processes. Again, taken-for-granted concepts, such as “the public” or “public participation,” are shown to be actively made through social processes. The insights from such an approach can help to inform the practice of public engagement by leading to alternative approaches to the design of engagement and participation.

4.3.2. Mobilized publics

A second approach to public engagement is the study of mobilized publics. This work builds on STS research on social movements and mobilized publics during the 1990s and early 2000s [48,49,122–124,141]. Subsequent research on energy and mobilized publics developed some new directions, such as the construction of mobilized publics, STS-informed rethinking of concepts in social movement theory, the role of counter-expertise in public mobilizations, and citizen science.

Consistent with the “construction of the public” perspective in the previous section, one approach focuses on the construction of mobilized publics. For example, research on opposition to off-shore wind energy on the island of Samsø, which is Denmark's renowned renewable energy island, showed that the official construction of local opposition as self-interested and insular NIMBYism precluded the potential for a more democratic politics of technology [142]. The limited approach to defining public opposition constricted potential outcomes to withdrawal of the project or to enforced implementation of the project over community objections. Rather than the view local opposition as self-interested NIMBYism, Papazu pointed to the opportunity to construct public opposition as a call for a more collaborative approach consistent with the island's history of successful onshore wind technology development.

Another approach to mobilized publics with an STS perspective involves interrogating how concepts in social movement studies might be altered as part of the engagement with STS. For example, a review of anti-dam movements in Brazil argued that the concept of an opportunity structure for social movements (the idea of how open or closed a government is to the claims of movements) needs to be broadened to include an epistemic dimension [143]. An important aspect of the epistemic dimension is the role of counter-expertise in scientized policy decision-making venues. As with other social movements and other mobilized publics, the anti-dam movements in Brazil cultivated both scientific and legal counter-expertise, especially when they were engaged in highly scientized venues such as environmental impact assessment processes. Likewise, a study of public comments on federal government policy for hydraulic fracturing in the U.S. brought the concept of boundary objects into the study of social movements and policy. This study showed how both industry and advocacy groups referenced government expertise and research even though the opposing actors had different interpretations of its implications [144].

In the articles reviewed, the analysis of counter-expertise was the main type of STS perspective on mobilized publics and energy. In some cases, scientists have been leaders of industrial opposition movements, such as their role in nuclear industry politics in Japan [145]. However, movements also recruit scientists to provide support, especially when movements are engaged in policy venues that require significant technical knowledge, and scientists can help movements to develop civic epistemologies to contest the official narratives of expertise [146].

One approach to the study of counter-expertise and mobilized publics has explored unforeseen consequences that occur when public participation is structured by scientized decision-making venues. For example, Anshelm and Galis showed how the anti-nuclear movement in Norway used support from counter-experts to draw attention to the lack of a solution to nuclear storage [147]. These criticisms nudged the state and industry to develop plans and technologies for nuclear waste storage and to develop a consultative process for nuclear siting. As plans developed for storage, the movement's counter-experts criticized the scientific dimensions of proposed plans, but they also criticized the industry's decision to proceed with nuclear waste storage based only on local political acceptance rather than on geological and other technical criteria. Thus, the reliance on counter-expertise, while successful at first, also led the movement to become caught up in the scientized web of scientific and technical arguments rather than maintaining its attention to broader political questions of the ultimate type of energy that was appropriate for the country. Paradoxically, doing so helped the nuclear industry to develop a global model of nuclear energy storage, and it may have helped the industry to achieve an outcome opposite to that originally desired by the movement.

Another approach to counter-expertise suggests that the emphasis of mobilized publics on cultivating and generating counter-expertise may be appropriate for liberal democracies in wealthy countries, but it may be less applicable to illiberal democracies and less wealthy countries. For example, Amir showed how the anti-nuclear movement in Indonesia focused on very general aspects of risk and uncertainty that drew attention to the limits of technical assurances of safety rather than getting caught up in highly scientized debates over nuclear energy safety [146]. These concerns included uncertainty arising from the lack of competence of the government to ensure safety standards and uncertainty based on unknowns about the frequency and effects of earthquakes and tsunamis, which are common in this seismically active area of the world. Likewise, in India scientists who spoke out against nuclear energy faced suppression, and when activists shifted to a litigation strategy, it also failed [148]. These failures led activists into a citizen science strategy, but not to develop scientific knowledge about risk and exposure. Instead, they tracked available information to detect instances of corruption in the nuclear establishment. Thus, although knowledge is still important for the mobilized publics in this case, it was different from scientific knowledge and closer to investigative journalism.

A third approach to counter-expertise focuses on how mobilized publics have generated their own research to address needs that they identify as undone science. A growing literature has emerged on citizen science, some of which covers energy and extractive technological systems [149,150]. One area of citizen science research focuses on community-based lay research and the creation of web portals with crowd-sourced databases [151,152]. In the process of developing these transparency projects, the citizen groups have helped to spur the government into releasing more information [98]. In some cases, STS researchers have also become involved in helping the communities to design citizen-based research projects, such as using a low-technology approach to monitoring chronic exposure from air pollution from oil and gas wells [153].

In summary, similar to work on public engagement processes, research on mobilized publics has begun with the question of how the public is defined and constructed. It problematizes the public by questioning the analysis of the public that is limited to the individual, layperson or non-expert, an approach that tends to be the basis of participation and consultation processes. Instead, the mobilized publics perspective draws attention to actors who actively shape public opinion and define a public interest on an issue. It also draws attention to the politics of scientized decision-making processes by generating research both on the use of counter-expertise by mobilized publics and on the limits of counter-expertise. Science in these fora is not envisioned as pure, dispassionate, or neutral; instead, science is entangled with politics, values, and an array of other social factors. This research also explores the role of “science at large” in political conflict over energy policy and energy futures, including the potential of diverse forms of citizen science and the development of alternative forms of knowledge (i.e., studies of corruption) anchored in local and lay perspectives.

4.4. Sociotechnical systems, practices, and users

STS researchers have argued that the perspective of sociotechnical systems helps to make visible aspects of energy that are hidden in other theoretical perspectives [154].This section will review some of the ways that the sociotechnical systems perspective is found in the energy-related literature, including studies of the systems themselves and of the role of users and practices in the deployment and operation of the systems. We include users in this section because they are a crucial part of sociotechnical systems. They attribute new meanings to sociotechnical systems and artifacts, and they also redesign them in everyday practices. As in STS-informed research on risk and standards, researchers who study sociotechnical systems came to appreciate that the constructive processes occurred not only at the upstream end of design and innovation but also downstream in the use of technology and in the consumer interface. This approach led to an increasing approximation between the analysis of users and general theoretical work on practices, which also attracted the interest of STS researchers [155]. Practice-oriented approaches generally draw attention to the embodied, materially connected aspects of human social life that are based on shared understandings and skill.

4.4.1. Large technological systems and the politics of design

Three longstanding STS perspectives on sociotechnical systems—large technological systems, social construction of technology, and the politics of design—were evident in the data set but not widely used. These perspectives date back to STS work on technology during the 1980s, specifically Hughes on large technological systems, Bijker and Pinch on the social construction of technology, and Winner on the politics of design [9,18,35].

Research on large technological systems—which Sovacool and colleagues described as sociotechnical, large, varied in form, and obdurate [156]—continued during the 1990s and expanded to include governance [52,54,157–159]. In this data set, an example of the large technological systems approach is work by Sovacool and colleagues, who extended and deepened the phase model of Hughes [9,156]. They noted that the original model did not include mature technological systems, and they delineated three additional processes that occur with mature systems: reconfiguration, contestation, and decline. Another new direction in the analysis of large technological systems was attention to the changes in the systems that involve decentralization and differentiation, a process that is occurring in electricity, water, and other systems [160]. A study of nuclear energy policy in Japan also synthesized the large, technological systems perspective with the advocacy coalition framework of policy studies [161].

In a study of natural gas pipelines as large technological systems, Sovacool drew on the related social construction of technology framework, specifically the concepts of relevant social groups and technological frames (the motivations and values of different groups). In this study, he explained why one large pipeline project proceeded quickly and another failed [162]. Despite interpretive flexibility in the sense that actors attributed different meanings and implications to proposed pipeline projects, in the successful case the relevant social groups developed an alignment of technological frames, whereas they failed to do so in the unsuccessful case.

Another STS perspective on sociotechnical systems is the politics of design, which examines the political and societal implications of design choices and differences. One approach is through work on mobilized publics that point to alternative ways of designing energy systems that are less prejudicial to workers, communities, and environments [163,164]. Another example of the politics of design is research that links different policy options for renewable energy and energy efficiency to political ideology, thus showing how attention to the design of energy systems can open or close political support from potential opponents such as conservative political party members. For example, energy-efficiency programs for government buildings can be less controversial politically with conservatives, who decry government spending, than subsidies for solar energy [165]. A third example is found in the above-mentioned study of anti-dam movements, which maps a range of “design conflicts” or definitional struggles over the technological systems and their governance [143]. Describing a layering of the politics of design, the analysis began with object conflicts (a subset of design conflicts focused on material design) involving the technical design of dams and the “to build or not to build” question. The study then discussed a broader range of conflicts involving the design of the governance of the systems, of remediation programs, and of the country's energy system. This approach suggested a nested, scalar approach to the politics of design that included both technological systems and governance processes.

There is also some innovative work that brings together the analysis of the politics of design perspective with research on imaginaries. In a study of imaginaries for the niche of bioenergy in the U.S. Northeast, Burnham and colleagues brought the analysis of imaginaries into conversation with both transition studies and the analysis of object conflicts [166]. They distinguished two innovation niches and associated imaginaries: a “community energy” niche, which emphasized local ownership and consumption, and a “regional production niche,” which emphasized larger-scale production for industrial uses. The imaginaries were associated with object conflicts over what constituted the local and the capacity of the niche to scale and have greater effects on the energy regime.

In summary, to some extent the sociotechnical perspectives in this section may be less novel in energy social science research because they have already been incorporated into research in the sustainability transitions field [167]. Also, because this group of STS perspectives often takes a sociotechnical system as the unit of analysis, they have been fruitfully applied to energy, transport, and related sectors. In other words, this area of STS research is an example of where STS perspectives have been thoroughly integrated into many energy social science studies. Nevertheless, there are also areas for additional contributions. For example, although policy studies in energy social science recognize how technological choices can be contested, the full range of the politics of design is not always explored. Moreover, relationships between multiple, competing LTSs—as they co-evolve, become layered, or clash with other systems—have been less studied, along with the deliberate destabilization of some undesirable LTSs (that is, how to intentionally stimulate their reconfiguration and decline).

4.4.2. Sociotechnical systems, users, and practices

In the energy and social science field, there is significant interest in users and practices, some of which is directly influenced by STS perspectives [168]. These perspectives draw attention to constructive processes, such as how users engage sociotechnical systems in pragmatic ways as active consumers who question, remake, and reinterpret the systems [169]. The approach suggests the need to attend to the agency of users, for example, their capacity to develop social networks that can share information that changes their interactions with sociotechnical systems [170]. Having a better understanding of the agency and creativity of users can be helpful to experts, advocates, and policymakers who hope to guide sociotechnical system development and transitions [171].

Another approach to the agency of users is the analysis of local differences in how sociotechnical systems are configured. For example, a comparative analysis of the smart grid and users in Norwegian communities showed how the relationship is structured differently according to local needs, values, and understandings [172]. Moreover, the consumer interface of the smart grid shows how elements of a sociotechnical system can serve as boundary objects that provide sufficient interpretive flexibility to mediate between the worlds of households, government policy, and the utilities [173].

Actor-network perspectives have also appeared in the literature on sociotechnical systems, users, and practices. From the actor-network perspective, energy systems orchestrate and enroll users in new practices but also generate challenges of complexity and overflowing that users actively engage and reduce [174,175]. One primary implication of an actor-network perspective in the study of practices is that it questions the assumption of the user of sociotechnical systems as an adult, human consumer. For example, Strengers and colleagues suggest that the assumption of user-as-adult-consumer misses the role of children, babies, the unwell, guests, pets, pests, and indoor plants [176]. Not only does this perspective recognize the intentionality, influence, and/or agency of other actors, but it also reconceptualizes agency as an "agentic capacity" that is distributed across a network through practices rather than located only in an adult human endowed with goals and planning. This perspective enabled creative empirical research questions on the role of other dimensions of household energy consumption that might have been missed with non-sociotechnical perspectives.

Another approach to the reconceptualization of the user as adult consumer is research that studies users' practices outside the domestic setting. Users engage with the same or similar technologies, such as building energy systems, in different ways depending on whether they are home or in the workplace [177]. As employees, they may also be in the role of monitoring sociotechnical systems, and in this role they have obligations to report on the system and on other system interactions with other users. For example, in research on reporting practices in a nuclear reactor, Rossignol began with accepted, institutionalized forms of reporting into a system and then showed how there was a drift to informal but legitimate reporting [178]. Finally, there was a "drift from the drift," where employees negotiated over-reporting and non-reporting with respect to perceived effects on solidarity and perceived levels of risk.

In summary, STS perspectives on users provide a similar framework to that discussed previously for imaginaries, risk, economic models, participation, and publics: these perspectives inspect a taken-for-granted concept of the "user," "adopter," or "consumer" and examine how it is made and remade in practice and how the user is coconstituted with the sociotechnical system. Thus, researchers have increasing explored alternative definitions of users (e.g., citizen, worker producer, and intermediary) and ways in which users reconfigure technological systems. For example, some users of photovoltaic systems in the U.S. see their choices as connected with environmentalism, opposition to fossil-fuel subsidies, and support for energy decentralization [179]. In this way, users connect their practices with broader institutional and political meanings and develop a politics of system design. This work can also involve the concept of the imaginary to develop critical analyses of how sociotechnical systems link users to the imaginaries of consumer convenience and "smartness" [180].

5. Discussion: opening the black box of sociotechnical matters

As indicated in the methods section, this structured review of STS perspectives in social science research on energy is based on a stratified sample of the literature (both STS and general energy social science publications) that has enabled the authors to develop a robust overview of the diversity of STS perspectives. We argue that there is no single STS perspective; rather, there are diverse perspectives that are linked together by a common STS sensibility that brings to light processes by which epistemic, social, and technological entities are made and are coconstituted with symbolic and environmental systems (see Fig. 3). More generally, STS perspectives share a sociotechnical perspective on the material dimensions of social life, which might otherwise be perceived as set apart or exogenous to the social.

As the circular arrows indicate in Fig. 3, the review also indicates some overlap and convergences among the perspectives. For example, the study of imaginaries was originally oriented toward the future-oriented visions associated with the energy policies of national governments, but it has expanded to include the imaginaries that scientists, industrial leaders, and government officials have of the public; the imaginaries of communities and mobilized publics; the imaginaries of

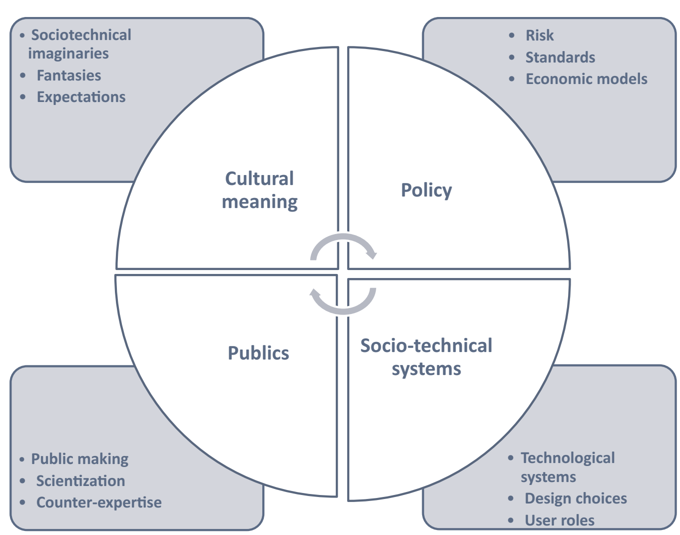

Fig. 3. Four core STS perspectives on energy with 12 interconnected subthemes.
Source: Authors.

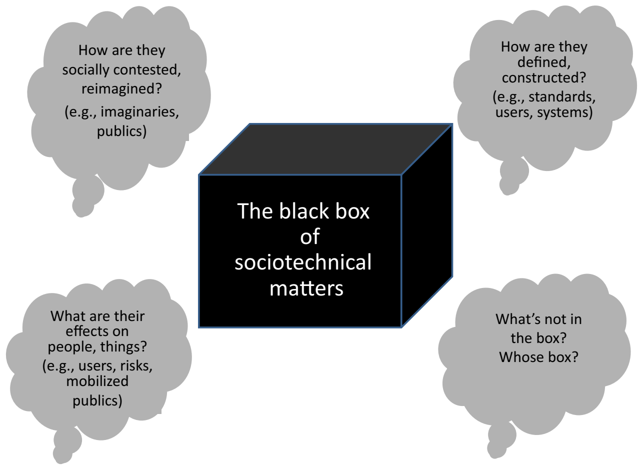

Fig. 4. The black box of sociotechnical matters opened up by science & technology studies.
Source: Authors.

companies and governments that develop and market sociotechnical systems such as the smart grid; and even the imaginaries of users. The study of sociotechnical systems has become integrated increasingly with practices and users, and in turn the analysis of practices and users has connected with actor-networks, imaginaries, and publics. Likewise, as actor-network and performativity approaches have become applied to policy, they have come to incorporate the analysis of mobilized publics that often contest the frames of economic rationality that have been established to justify and stabilize sociotechnical arrangements. Thus, the review indicates not only the existence of diverse perspectives but also some examples of hybridization and opportunities for future synthesis.

Moreover, the sum becomes potentially more than its parts and also more than the points of connection and overlap among the perspectives. As noted in the introduction, STS perspectives pay attention to what other research fields may leave in the "black box" of the unexamined nexus of social and technical matters. From this *doxa* of the STS field, a wide range of topics and questions emerges. (See Fig. 4.) For example, STS provides a sensibility that involves asking how sociotechnical matters are defined, constructed, maintained, and shaped; what the effects are on social arrangements, social structures, and indeed on the imbrications, agencements, coconstitution, mutual shaping, coconstruction, or coproduction of the social and technical orders; the ways in which the sociotechnical matters can become sites of questioning, reinterpretation, reconstruction, and contestation; and the deeper, reflexive sociological questions that ask what is in the black box and what is excluded from it [181,182].

This last question, "What's not in the box?" becomes more salient when one steps back from the overview of diverse STS perspectives. In addition to providing a map of and ways into the literature, a good review also provides an opportunity to ask some questions about the future direction of a research field, in the tradition of Sovacool's question: "What are we doing here?" [183]. With the goal of integration but also exploration in mind, the four thematic areas of discourse, policy, publics, and sociotechnical systems are not exhaustive. Although they reflect the dominant uses of STS work so far, they also provide a basis for the researchers to ponder new directions. For example, there is growing attention to interventionist approaches and participant-action research in STS, especially with respect to environmental justice, and likewise there is growing attention to energy justice and energy democracy in energy social science research. These approaches may become increasingly relevant in the energy-STS nexus as well.

6. Conclusion

As the nexus of research exploring the intersections of STS and energy social science continues to develop, opportunities emerge not only for the application of STS perspectives but also for their further refinement and development. STS can inform researchers who study energy topics, but research on energy can further challenge STS concepts, applications, and interpretations. In part, the opportunities transpire because there are differences of emphasis between the study of energy in the STS literature and in STS-informed research in the energy social science literature. For example, in STS, research on energy has tended to emphasize expertise, especially as found in research on publics and participation. This pattern makes a degree of sense because in the STS field there has long been a supplementary relationship between science and technology, where technology studies is the secondary field, and science and expertise receive more attention. In energy social science research, technology looms large; indeed, technology and its governance and practices are more central in energy social science. The differences in focus may provide opportunities for rethinking the science-technology relationship in the construction of energy-related research agendas in the STS field.

Specifically, it is valuable to view the attention to technology in energy social science research not merely as an indication that it is an applied field where STS concepts are used to serve policy-relevant work on energy problems. Rather, underlying much STS thinking is a way of thinking that applies equally to science and technology: attention to processes of coconstruction or the mutual shaping of social, material, and epistemic orders; an appreciation for self-reflection, deconstruction, and critique; a tolerance or even celebration of diversity; and a commitment to imagining a future world that is better than the one we currently have.

Furthermore, energy social science research that uses STS perspectives can also be a site for theoretical testing, refinement, development, and innovation. One model of the development of STS concepts occurs in sustainability transitions studies, where some of the most creative theoretical work on sociotechnical systems after the year 2000 has been accomplished [167]. The field has demonstrated the potential for hybridization and theoretical innovation between STS and the innovation studies literature, and currently there is also integration with policy process theories and institutional theory [184,185]. There is also creative work on deep transitions [186] and transformative innovation [187]. Similar opportunities may now be available for the theoretical advancement at the intersections of STS and energy social science research.

Thus, the open intellectual terrain of energy social science provides fertile ground for the hybridization of STS perspectives with other perspectives in the social sciences. For example, there is an opportunity to connect STS concepts and frameworks with growing interest in energy studies in energy justice, framing and discourse coalitions, global inequality, gender and race, democracy, sustainability, and different users. In the papers reviewed here, there are intriguing glimpses of a future black box that is more oriented toward this intellectual terrain, among them the study of contested imaginaries, risk, and standards; of work on assemblages that overflow from unintended consequences and public discontent; of new forms of expert-public relations that might open pathways to more democratic engagement rather than legitimation of the status quo; of an expanded analysis of expertise, knowledge, technology, and mobilized publics; of a reinvigorated and expanded analysis of the politics of design of sociotechnical systems; and of new ways of envisioning the user as a citizen and policy actor. These promising developments help to situate STS perspectives as relevant to broad interdisciplinary and even societal conversations that are connected with pressing global problems. Thus, we see the interface of STS and energy social science not as a distinction between a theoretical and applied field but as an interdisciplinary nexus where both fields can advance via new conceptual hybrids and new research agendas.

Although the topics, themes, and methods of STS research and energy social science may not always be commensurate or compatible, STS approaches can certainly illuminate the complex, and compelling, relationship between humans and the energy infrastructures and material realities they seek to build. By analyzing the coconstruction of technology and society, even when STS approaches cannot necessarily unify, they can creatively clarify.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

There was no outside funding for this study.

References

[1] Eds. U. Felt, R. Fouché, C. Miller, L. Smith-Doerr (Eds.), Handbook of Science and Technology Studies, MIT Press, Cambridge, USA, 2017.
[2] Ed. S. Harding (Ed.), The Postcolonial Science and Technology Studies Reader, Duke University Press, Durham, USA, 2011.
[3] Eds. D. Kleinman, K. Moore (Eds.), The Routledge Handbook of Science, Technology and Society, Routledge, London, 2014.
[4] Eds. D. Tyfield, R. Lave, S. Randalls, C. Thorpe (Eds.), The Routledge Handbook of the Political Economy of Science, Routledge, New York, USA, 2017.
[5] D. Hess, Science Studies: An Advanced Introduction, New York University Press, New York, USA, 1997.
[6] D. Kleinman, Science and Technology in Society: From Biotechnology to the Internet, Blackwell, Malden, USA, 2005.
[7] S. Sismondo, An Introduction to Science and Technology Studies, Wiley-Blackwell, Malden, USA, 2010.
[8] S. Yearley, Making Sense of Science: Understanding the Social Studies of Science, Sage, Thousand Oaks, USA, 2005.
[9] T. Hughes, The evolution of large technological systems, Eds. in: W. Bijker, T. Hughes, T. Pinch (Eds.), The Social Construction of Technological systems: New directions in the Sociology and History of Technology, MIT Press, Cambridge, USA, 1987, pp. 51–82.
[10] L. Winner, Do artifacts have politics? Daedalus 109 (1) (1980) 121–136.
[11] B. Wynne, Misunderstood misunderstanding: social identities and public uptake of science, Public Underst. Sci. 1 (3) (1992) 281–304.
[12] J. Ellul, The Technological Society, Knopf, New York, 1964.
[13] A. Feenberg, Critical Theory of Technology, Oxford University Press, 1991.
[14] H. Marcuse, One Dimensional Man, McGraw Hill, New York, 1962.
[15] L. Mumford, Technics and Civilization, Routledge and Kegan Paul, London, 1934.
[16] L. Mumford, Authoritarian and democratic technics, Technol. Cult. 5 (1) (1964) 1–8.
[17] L. Winner, Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought, MIT Press, Cambridge, USA, 1978.
[18] L. Winner, The Whale and the Reactor, University of Chicago Press, Chicago, 1986.
[19] R. Merton, The Sociology of Science: Theoretical and Empirical Investigations, University of Chicago Press, Chicago, USA, 1973.
[20] T. Kuhn, The Structure of Scientific Revolutions, University of Chicago Press, Chicago, USA, 1962.
[21] Eds. I. Lakatos, A. Musgrave (Eds.), Criticism and the Growth of Knowledge, Cambridge University Press, Cambridge, UK, 1970.
[22] D. Bloor, Knowledge and Social Imagery, University of Chicago Press, Chicago, USA, 1976.
[23] H. Collins, Changing Order: Replication and Induction in Scientific Practice, University of Chicago Press, Chicago, USA, 1985.
[24] D. MacKenzie, Statistical theory and social interests: a case-study, Soc. Stud. Sci. 8 (1) (1978) 35–83.
[25] D. MacKenzie, Interests, positivism and history, Soc. Stud. Sci. 11 (4) (1981) 498–504.
[26] S. Woolgar, Interests and explanation in the social study of science, Soc. Stud. Sci. 11 (3) (1981) 365–394.
[27] P. Bourdieu, The Political Ontology of Martin Heidegger, Stanford University Press, Palo Alto, CA, 1991.
[28] D. Haraway, Primate Visions: Gender, Race, and Nature in the World of Modern Science, Routledge, London, 1989.
[29] S. Traweek, Beamtimes and Lifetimes: The World of High-Energy Physics, Harvard University Press, Cambridge, USA, 1988.
[30] K. Knorr-Cetina, M. Mulkay, Science Observed: Perspectives on the Social Study of Science, Sage, Beverly Hills, USA, 1983.
[31] T. Gieryn, Boundary-work and the demarcation of science from non-science: strains and interests in professional ideologies of scientists, Am. Soc. Rev. 48 (6) (1983) 781–795.
[32] S. Star, J. Griesemer, Institutional ecology, translations' and boundary objects: amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907-39, Soc. Stud. Sci. 19 (3) (1989) 387–420.
[33] S. Harding, The Science Question in Feminism, Cornell University Press, Ithaca, USA, 1986.
[34] S. Harding, Rethinking standpoint epistemology: what is" strong objectivity? Centen. Rev. 36 (3) (1992) 437–470.
[35] W. Bijker, T. Hughes, Eds. T.Pinch, The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology, MIT Press, Cambridge, USA, 1987.
[36] A. Feenberg, Questioning Technology, Routledge, 1999.
[37] Eds. D. MacKenzie, J. Wajcman (Eds.), The Social Shaping of Technology, Open University Press, Philadelphia, USA, 1985.
[38] S. Harding, Is Science Multicultural? Postcolonialisms, Feminisms, and Epistemologies, Indiana University Press, Bloomington, USA, 1998.
[39] D. Hess, Science and Technology in a Multicultural World: The Cultural Politics of Facts and Artifacts, Columbia University Press, New York, 1995.
[40] J. Wacjman, Feminism Confronts Technology, Penn State Press, University Park, USA, 1991.
[41] G. Bowker, S. Star, Sorting Things Out: Classification and Its Consequences, The MIT Press, Cambridge, USA, 1999.
[42] D. Guston, Stabilizing the boundary between US politics and science: the role of the office of technology transfer as a boundary organization, Soc. Stud. Sci. 29 (1) (1999) 87–111.
[43] S. Jasanoff, The Fifth Branch: Science Advisers As Policymakers, Harvard University Press, Cambridge, USA, 1990.
[44] M. Callon, Introduction: the embeddedness of economic markets in economics, Ed. in: M. Callon (Ed.), Laws of the Markets, Blackwell Publishers, Oxford, UK, 1998, pp. 1–57.
[45] B. Latour, The Pasteurization of France, Harvard University Press, Cambridge, USA, 1988.
[46] B. Latour, We Have Never Been Modern, Harvard University Press, Cambridge, USA, 1993.
[47] J. Law, After ANT: complexity, naming and topology, Sociol. Rev. 47 (S1) (1999) 1–4.
[48] A. Clarke, Disciplining Reproduction: Modernity, American Life Sciences, and "The Problems of Sex, University of California Press, Berkeley, USA, 1998.
[49] S. Epstein, Impure Science: AIDS, Activism, and the Politics of Knowledge, University of California Press, Berkeley, USA, 1996.
[50] Eds. A. Irwin, B. Wynne (Eds.), Misunderstanding Science? The Public Reconstruction of Science and Technology, Cambridge University Press, Cambridge, USA, 1996.
[51] W. Bijker, Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change, MIT Press, Cambridge, USA, 1995.
[52] O. Coutard, The Governance of Large Technical Systems, Routledge, London, 1999.
[53] T. Hughes, Networks of Power: Electrification in Western Society, 1880-1930, Johns Hopkins University Press, Baltimore, USA, 1993.
[54] Ed. J. Summerton (Ed.), Changing Large Technical Systems, Westview Press, Boulder, USA, 1994.
[55] N. Oudshoorn, T. Pinch, How Users Matter: The Co-Construction of Users and Technologies, MIT Press, Cambridge, USA, 2003.
[56] R. Kemp, J. Schot, R. Hoogma, Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management, Technol. Anal. Strateg. 10 (2) (1998) 175–198.
[57] J. Schot, Constructive technology assessment and technology dynamics: the case of clean technologies, Sci. Technol. Hum. Val. 17 (1) (1992) 36–56.
[58] J. Schot, A. Rip, The past and future of constructive technology assessment, Technol. Forecast. Soc. 54 (2–3) (1997) 251–268.
[59] F. Geels, Feelings of discontent and the promise of middle range theory for STS: examples from technology dynamics, Sci. Technol. Hum. Val. 32 (6) (2007) 627–651.
[60] F. Geels, Transformations of large technical systems: a multilevel analysis of the Dutch highway system (1950-2000), Sci. Technol. Hum. Val. 32 (2) (2007) 123–149.
[61] M. Burke, J. Stephens, Political power and renewable energy futures: a critical review, Energy Res. Soc. Sci. 35 (2018) 78–93.
[62] T. Hoppe, F. Coenen, M. van den Berg, Illustrating the use of concepts from the discipline of policy studies in energy research: an explorative literature review, Energy Res. Soc. Sci. 21 (2016) 12–32.
[63] K. Isoaho, K. Karhunmaa, A critical review of discursive approaches in energy transitions, Energ. Policy 128 (2019) 930–942.
[64] K. Charmaz, The power of constructivist grounded theory for critical inquiry, Qual. Inq. 23 (1) (2017) 34–45.
[65] S. Jasanoff, Ordering knowledge, ordering society, Ed. in: S. Jasanoff (Ed.), States of Knowledge: The Co-Production of Science and Social Order, Routledge, New York, 2004, pp. 13–45.
[66] C. Miller, C. Wyborn, Co-production in global sustainability: histories and theories, Environ. Sci. Policy (2020) in press.
[67] Eds. L. Layne, S. Vostral, K. Boyer (Eds.), Feminist Technology, University of Illinois Press, Champaign-Urbana, USA, 2010.
[68] Ed. G. Marcus (Ed.), Technoscientific Imaginaries: Conversations, Profiles, Memoirs, University of Chicago Press, Chicago, USA, 1994.
[69] C. Taylor, Modern Social Imaginaries, Duke University Press, Durham, USA, 2004.
[70] C. Groves, Emptying the future: on the environmental politics of anticipation, Futures 92 (2017) 29–38.
[71] S. Jasanoff, Future imperfect: science, technology, and the imaginations of

modernity, Eds. in: S. Jasanoff, H. Kim (Eds.), Dreamscapes of Modernity. Sociotechnical Imaginaries and the Fabrication of Power, University of Chicago Press, Chicago, 2015, pp. 1–33.
[72] L. Levidow, T. Papaioannou, State imaginaries of the public good: shaping uk innovation priorities for bioenergy, Environ. Sci. Policy 30 (2013) 36–49.
[73] B. Sovacool, M. Ramana, Back to the future: small modular reactors, nuclear fantasies, and symbolic convergence, Sci. Technol. Hum. Val. 40 (1) (2015) 96–125.
[74] Eds. G. Verschraegen, F. Vandermoere, L. Braeckmans, B. Segaert (Eds.), Imagined Futures in Science, Technology and Society, Taylor & Francis, London, 2017.
[75] S. Jasanoff, S.-H. Kim, Containing the atom: sociotechnical imaginaries and nuclear power in the United States and South Korea, Minerva 47 (2) (2009) 119–146.
[76] C. Miller, New civic epistemologies of quantification: making sense of indicators of local and global sustainability, Sci. Technol. Hum. Val. 30 (3) (2005) 403–432.
[77] N. Longhurst, J. Chilvers, Mapping diverse visions of energy transitions: co-producing sociotechnical imaginaries, Sustain. Sci. (2019) 1–18.
[78] S. Jasanoff, S.-.H. Kim, Sociotechnical imaginaries and national energy policies, Sci. Cult. 22 (2) (2013) 189–196.
[79] A. Tidwell, J. Smith, Morals, materials, and technoscience: the energy security imaginary in the United States, Sci. Technol. Hum. Val. 40 (5) (2015) 687–711.
[80] C. Yang, B. Szerszynski, B. Wynne, The making of power shortage: the socio-technical imaginary of nationalist high modernism and its pragmatic rationality in electricity planning in Taiwan, East Asian Sci. Technol. Soc 12 (3) (2018) 277–308.
[81] D. Hess, Publics as threats? Integrating science and technology studies and social movement studies, Sci. Cult. 24 (1) (2015) 69–82.
[82] S.-.H. Kim, Social movements and contested imaginaries in South Korea, Eds. in: S. Jasanoff, S.-H Kim (Eds.), Dreamscapes of Modernity. Sociotechnical Imaginaries and the Fabrication of Power, University of Chicago Press, Chicago, 2015, pp. 152–173.
[83] J. Marquardt, L. Delina, Reimagining energy futures: contributions from community sustainable energy transitions in Thailand and the Philippines, Energy Res. Soc. Sci. 49 (2019) 91–102.
[84] H. Simmet, Lighting a dark continent: imaginaries of energy transition in Senegal, Energy Res. Soc. Sci. 40 (2018) 71–81.
[85] J. Smith, A. Tidwell, The everyday lives of energy transitions: contested sociotechnical imaginaries in the American West, Soc. Stud. Sci. 46 (3) (2016) 327–350.
[86] S. Zilliox, J. Smith, Colorado's fracking debates: citizen science, conflict and collaboration, Sci. Cult. 27 (2) (2018) 221–241.
[87] Y. Fatimah, Fantasy, values, and identity in biofuel innovation: examining the promise of Jatropha for Indonesia, Energy Res. Soc. Sci 7 (2015) 108–116.
[88] B. Sovacool, B. Brossmann, Fantastic futures and three American energy transitions, Sci. Cult. 22 (2) (2013) 204–212.
[89] H. Kim, S. Cho, S. Song, Wind, power, and the situatedness of community engagement, Public Underst. Sci. 28 (1) (2019) 38–52.
[90] D. Hess, Coalitions, framing, and the politics of energy transitions: local democracy and community choice in California, Energy Res. Soc. Sci 50 (2019) 38–50.
[91] D. Rosenbloom, Framing low-carbon pathways: a discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario, Environ. Innov. Soc. Trans. 27 (2018) 129–145.
[92] U. Beck, Risk Society: Towards a New Modernity, Sage, London, 1991.
[93] B. Wynne, Uncertainty and environmental learning: reconceiving science and policy in the preventive paradigm, Global Environ. Chang 2 (2) (1992) 111–127.
[94] S. Timmermans, M. Berg, Standardization in action: achieving local universality through medical protocols, Soc. Stud. Sci. 27 (2) (1997) 273–305.
[95] Y. Fujigaki, The processes through which nuclear power plants are embedded in political, economic, and social contexts in Japan, Ed. in: Y. Fujigaki (Ed.), Lessons from Fukushima: Japanese Case Studies on Science, Technology and Society, Springer, Cham, Switzerland, 2015, pp. 7–25.
[96] E. Howell, C. Wirz, D. Brossard, D. Scheufele, M. Xenos, Seeing through risk-colored glasses: risk and benefit perceptions, knowledge, and the politics of fracking in the United States, Energy Res. Soc. Sci. 55 (2019) 168–178.
[97] C. O'Connor, K. Fredericks, Citizen perceptions of fracking: the risks and opportunities of natural gas development in Canada, Energy Res. Soc. Sci. 42 (2018) 61–69.
[98] A. Kinchy, G. Schaffer, Disclosure conflicts: crude oil trains, fracking chemicals, and the politics of transparency, Sci. Technol. Hum. Val. 43 (6) (2018) 1011–1038.
[99] R. Sidortsov, Reinventing rules for environmental risk governance in the energy sector, Energy Res. Soc. Sci. 1 (2014) 171–182.
[100] A. Goldthau, Rethinking the governance of energy infrastructure: scale, decentralization and polycentrism, Energy Res. Soc. Sci. 1 (2014) 134–140.
[101] T. Morris-Suzuki, Touching the grass: science, uncertainty and everyday life from Chernobyl to Fukushima, Sci. Technol. Soc. 19 (3) (2014) 331–362.
[102] A. Kimura, Citizen science in post-Fukushima Japan: the gendered scientization of radiation measurement, Sci. Cult. (2017) 1–24.
[103] D. Winickoff, M. Mondou, The problem of epistemic jurisdiction in global governance: the case of sustainability standards for biofuels, Soc. Stud. Sci 47 (1) (2017) 7–32.
[104] L. Levidow, E.U. criteria for sustainable biofuels: accounting for carbon, depoliticising plunder, Geoforum 44 (2013) 211–223.
[105] J. Kester, L. Noel, X. Lin, G. de Rubens, B. Sovacool, The coproduction of electric mobility: selectivity, conformity and fragmentation in the sociotechnical acceptance of vehicle-to-grid (V2G) standards, J. Clean. Prod. 207 (2019) 400–410.
[106] R Shaw, R. Ozaki, Emergent practices of an environmental standard, Sci. Technol. Hum. Val. 41 (2) (2016) 219–242.
[107] L. Müller, The legal dwelling: how Norwegian research engineers domesticate construction law, Eng. Stud. 7 (1) (2015) 80–98.
[108] M. Iskandarova, From the idea of scale to the idea of agency: an actor-network theory perspective on policy development for renewable energy, Sci. Publ. Policy 44 (4) (2016) 476–485.
[109] H. Yang, Reassembling solar farms, reassembling the social: a case study of Ping-Tung county in southern Taiwan, East Asian Sci. Technol. Soc. 9 (4) (2015) 359–379.
[110] Eds. D. MacKenzie, F. Muniesa, L. Siu (Eds.), Do Economists Make Markets? On the Performativity of Economics, Princeton University Press, Princeton, USA, 2007.
[111] A. Silvast, Energy, economics, and performativity: reviewing theoretical advances in social studies of markets and energy, Energy Res. Soc. Sci. 34 (2017) 4–12.
[112] M. Callon, An essay on framing and overflowing: economic externalities revisited by sociology, Soc. Rev. 46 (1_suppl) (1998) 244–269.
[113] Y. Rydin, L. Natarajan, M. Lee, S. Lock, Black-boxing the evidence: planning regulation and major renewable energy infrastructure projects in England and Wales, Plan. Theor. Pract. 19 (2) (2018) 218–234.
[114] B. Cointe, Managing political market agencements: solar photovoltaic policy in France, Environ. Polit. 26 (3) (2017) 480–501.
[115] E. Jolivet, E. Heiskanen, Blowing against the wind: an exploratory application of actor network theory to the analysis of local controversies and participation processes in wind energy, Energ. Policy 38 (2010) 6746–6754.
[116] C. Alvial-Palavicino, S. Ureta, Economizing justice: turning equity claims into lower energy tariffs in Chile, Energ. Policy 105 (2017) 642–647.
[117] M. Åkerman, T. Peltola, How does natural resource accounting become powerful in policymaking? A case study of changing calculative frames in local energy policy in Finland, Ecol. Econ. 80 (2012) 63–69.
[118] D. Breslau, Designing a market-like entity: economics in the politics of market formation, Soc. Stud. Sci. 43 (2013) 829–851.
[119] Eds. J. Chilvers, M. Kearnes (Eds.), Remaking Participation: Science, Environment, and Emergent Publics, Routledge, London, 2015.
[120] Eds. L. Phillips, A. Carvalho, J. Doyle (Eds.), Citizen Voices: Performing Public Participation in Science and Environment Communication, Intellect Books, Bristol, UK, 2012.
[121] P. Brown, Popular epidemiology and toxic waste contamination: lay and professional ways of knowing, J. Health Soc. Behav. 33 (3) (1992) 267–281.
[122] P. Brown, Toxic Exposures: Contested Illnesses and the Environmental Health Movement, Columbia University Press, New York, 2007.
[123] D. Hess, Alternative Pathways in Science and Industry, MIT Press, Cambridge, USA, 2007.
[124] A. Irwin, Citizen Science: A Study of People, Expertise and Sustainable Development, Routledge, London, 2002.
[125] J. Chilvers, N. Longhurst, Participation in transition(s): reconceiving public engagements in energy transitions as co-produced, emergent and diverse, J. Environ. Pol. Plan. 18 (5) (2016) 585–607.
[126] M. Aitken, Wind power planning controversies and the construction of “expert” and “lay” knowledges, Sci. Cult. 18 (1) (2009) 47–64.
[127] J. Barnett, K. Burningham, G. Walker, N. Cass, Imagined publics and engagement around renewable energy technologies in the UK, Public Underst. Sci. 21 (1) (2012) 36–50.
[128] M. Cotton, P. Devine-Wright, Making electricity networks “visible”: industry actor representations of “publics” and public engagement in infrastructure planning, Public Underst. Sci. 21 (1) (2012) 17–35.
[129] R. Hindmarsh, Wind farms and community engagement in Australia: a critical analysis for policy learning, East Asian Sci. Technol. Soc. 4 (4) (2010) 541–563.
[130] J. Chilvers, H. Pallett, T. Hargreaves, Ecologies of participation in socio-technical change: the case of energy system transitions, Energy Res. Soc. Sci. 42 (2018) 199–210.
[131] I. Welsh, B. Wynne, Science, scientism and imaginaries of publics in the UK: passive objects, incipient threats, Sci. Cult. 22 (4) (2013) 540–566.
[132] M. Ryghaug, T. Skjølsvold, S. Heidenreich, Creating energy citizenship through material participation, Soc. Stud. Sci. 48 (2) (2018) 283–303.
[133] P. Devine-Wright, Energy citizenship: psychological aspects of evolution in sustainable energy technologies, Ed. in: J. Murphy (Ed.), Governing Technology for Sustainability, Earthscan, London, 2007, pp. 63–88.
[134] W. Eaton, M. Burnham, C. Hinrichs, T. Selfa, Bioenergy experts and their imagined “obligatory publics” in the United States: implications for public engagement and participation, Energy Res. Soc. Sci. 25 (2017) 65–75.
[135] S. Heidenreich, Outreaching, outsourcing, and disembedding: how offshore wind scientists consider their engagement with society, Sci. Technol. Hum. Val. 43 (3) (2018) 464–486.
[136] S. Saarela, From pure science to participatory knowledge production? researchers' perceptions on science–policy interface in bioenergy policy, Sci. Publ. Policy 46 (1) (2018) 81–90.
[137] S. Davies, C. Selin, Energy futures: five dilemmas of the practice of anticipatory governance, Environ. Comm. 6 (1) (2012) 119–136.
[138] M. Entradas, Experimenting with distributed approaches; case study: a “national-level” distributed dialogue on bioenergy in the United Kingdom, Public Underst. Sci. 25 (4) (2016) 490–498.
[139] R. Phadke, Public deliberation and the geographies of wind justice, Sci. Cult. 22 (2) (2013) 247–255.
[140] M. Kattirtzi, Providing a “challenge function”: government social researchers in the UK's department of energy and climate change (2010–2015), Palgrave Commun. 2 (1) (2016) 16064.
[141] K. Moore, Organizing integrity: American science and the creation of public interest organizations, Am. J. Soc. 101 (6) (1996) 1592–1627.

[142] I. Papazu, Nearshore wind resistance on Denmark's renewable energy island: not another Nimby story, Sci. Technol. Stud 30 (1) (2017) 4–24.
[143] D. Hess, The anti-dam movement in Brazil: expertise and design conflicts in an industrial transition movement, Tapuya: Lat. Am. Sci. Technol. Soc. 1 (1) (2018) 256–279.
[144] J. Baka, A. Hesse, E. Weinthal, K. Bakker, Environmental knowledge cartographies: evaluating competing discourses in U.S. hydraulic fracturing rulemaking, Ann. Am. Assoc. Geog. 109 (6) (2019) 1941–1960.
[145] S. Avenell, Antinuclear radicals: scientific experts and antinuclear activism in Japan, Sci. Technol. Stud 21 (1) (2016) 88–109.
[146] S. Amir, Challenging nuclear: antinuclear movements in post-authoritarian Indonesia, East Asian Sci. Technol. Soc. 3 (2–3) (2009) 343–366.
[147] J. Anshelm, V. Galis, The politics of high-level nuclear waste management in Sweden: confined research versus research in the wild, Environ. Policy Gov 19 (4) (2009) 269–280.
[148] M. Haines, Contested credibility economies of nuclear power in India, Soc. Stud. Sci. 49 (1) (2019) 29–51.
[149] A. Kimura, A. Kinchy, Science by People: Participation, Power, and the Politics of Environmental Knowledge, Rutgers University Press, New Brunswick, NJ, USA, 2019.
[150] A. Kinchy, R. Phadke, Engaging the underground: images from a field in formation, Engaging Sci. Technol. Soc. 4 (2018) 22–42.
[151] K. Jalbert, S. Rubright, K. Edelstein, The civic informatics of fractracker alliance: working with communities to understand the unconventional oil and gas industry, Engaging Sci. Technol. Soc 3 (2017) 528–559.
[152] G. Ottinger, Crowdsourcing undone science, Engaging Sci. Technol. Soc. 3 (2017) 560–574.
[153] S. Wylie, E. Wilder, L. Vera, D. Thomas, M. McLaughlin, Materializing exposure: developing an indexical method to visualize health hazards related to fossil fuel extraction, Engaging Sci. Technol. Soc. 3 (2017) 426–463.
[154] C. Miller, A. Iles, C. JonesC.F., The social dimensions of energy transitions, Sci. Cult. 22 (2) (2013) 135–148.
[155] Eds. K. Knorr-Cetina, T. Schatzki, E. Von Savigny (Eds.), The Practice Turn in Contemporary Theory, Routledge, London, 2001.
[156] B. Sovacool, K. Lovell, M. Ting, Reconfiguration, contestation, and decline: conceptualizing mature large technical systems, Sci. Technol. Hum. Val. 43 (6) (2018) 1066–1097.
[157] I. Gökalp, On the analysis of large technical systems, Sci. Technol. Hum. Val. 17 (1) (1992) 57–78.
[158] Ed. T. LaPorte (Ed.), Social Responses to Large Technical Systems: Control or Anticipation, Kluwer Academic, London, UK, 1991.
[159] E. Van der Vleuten, Infrastructures and societal change: a view from the large technical systems field, Technol. Anal. Strateg. 16 (3) (2004) 395–414.
[160] B. van Vliet, Sustainable innovation in network-bound systems: implications for the consumption of water, waste water and electricity services, J. Environ. Pol. Plan. 14 (3) (2012) 263–278.
[161] J. Sklarew, Power fluctuations: how Japan's nuclear infrastructure priorities influence electric utilities' clout, Energy Res. Soc. Sci. 41 (2018) 158–167.
[162] B. Sovacool, Exploring the conditions for cooperative energy governance: a comparative study of two Asian pipelines, Asian Stud. Rev. 34 (4) (2010) 489–511.
[163] D. Mulvaney, Opening the black box of solar energy technologies: exploring tensions between innovation and environmental justice, Sci. Cult. 22 (2) (2013) 230–237.
[164] G. Ottinger, The winds of change: environmental justice in energy transitions, Sci. Cult 22 (2) (2013) 222–229.
[165] D. Hess, Q. Mai, K. Brown, Red states, green laws: ideology and renewable energy legislation in the United States, Energy Res. Soc. Sci. 11 (2016) 19–28.
[166] M. Burnham, W. Eaton, T. Selfa, C. Hinrichs, A. Feldpausch-Parker, The politics of imaginaries and bioenergy sub-niches in the emerging Northeast US bioenergy economy, Geoforum 82 (2017) 66–76.
[167] J. Köhler, F. Geels, F. Kern, E. Onsongo, A.J. Wieczorek, F. Alkemade, F. Avelino, A. Bergek, F. Boons, L. Fuenfschilling, D. Hess, G. Holtz, S. Hyysalo, K. Jenkins, P. Kivimaa, J. Markard, M. Martiskainen, A. McMeekin, M. Mühlemeier, B. Nykvist, B. Pel, R. Raven, H. Rohracher, B. Sanden, J. Schot, B. Sovacool, B. Turnheim, J. van den Bergh, D. Welch, P. Wells, An agenda for sustainability transitions research: state of the art and future directions, Environ. Innov. Soc. Trans. 31 (2019) 1–32.
[168] S. Guy, E. Shove, The Sociology of Energy, Buildings and the Environment: Constructing Knowledge, Designing Practice, Routledge, London, 2014.
[169] E. Judson, S. Bell, H. Bulkeley, G. Powells, S. Lyon, The co-construction of energy provision and everyday practice: integrating heat pumps in social housing in England, Sci. Technol. Stud. 28 (3) (2015) 26–53.
[170] S. Hyysalo, K. Juntunen, S. Freeman, Internet forums and the rise of the inventive energy user, Sci. Technol. Stud. 26 (1) (2013) 25–51.
[171] L. Schick, B. Winthereik, Innovating relations–or why smart grid is not too complex for the public, Sci. Technol. Stud. 26 (3) (2013) 82–102.
[172] T. Skjølsvold, M. Ryghaug, Embedding smart energy technology in built environments: a comparative study of four smart grid demonstration projects, Indoor Built Environ 24 (7) (2015) 878–890.
[173] H. Lovell, M. Pullinger, J. Webb, How do meters mediate? energy meters, boundary objects and household transitions in Australia and the United Kingdom, Energy Res. Soc. Sci. 34 (2017) 252–259.
[174] T. Skjølsvold, W. Throndsen, M. Ryghaug, I. Fjellså, G. Koksvik, Orchestrating households as collectives of participation in the distributed energy transition: new empirical and conceptual insights, Energy Res. Soc. Sci. 46 (2018) 252–261.
[175] A. Silvast, M. Virtanen, Keeping systems at work: electricity infrastructure from control rooms to household practices, Sci. Technol. Stud. 27 (2) (2014) 93–114.
[176] Y. Strengers, L. Nicholls, C. Maller, Curious energy consumers: humans and nonhumans in assemblages of household practice, J. Consum. Cult. 16 (3) (2016) 761–780.
[177] J. Palm, S. Darby, The meanings of practices for energy consumption–a comparison of homes and workplaces, Sci. Technol. Stud. 27 (2) (2014) 72–92.
[178] N. Rossignol, Practices of incident reporting in a nuclear research center: a question of solidarity, Safety Sci. 80 (2015) 170–177.
[179] C. Schelly, What's political about solar electric technology? The user's perspective, Engaging Sci. Technol. Soc. 1 (2015) 25–46.
[180] C. Groves, K. Henwood, F. Shirani, C. Butler, K. Parkhill, N. Pidgeon, The grit in the oyster: using energy biographies to question socio-technical imaginaries of “smartness, J. Respons. Innov. 3 (1) (2016) 4–25.
[181] S. Harding, Whose Science? Whose Knowledge? Thinking from Women's Lives, Cornell University Press, Ithaca, USA, 1991.
[182] L. Winner, Upon opening the black box and finding it empty: social constructivism and the philosophy of technology, Sci. Technol. Hum. Val. 18 (3) (1993) 362–378.
[183] B. Sovacool, What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda, Energy Res. Soc. Sci. 1 (2014) 1–29.
[184] P. Andrews-Speed, Applying institutional theory to the low-carbon energy transition, Energy Res. Soc. Sci. 13 (2016) 216–225.
[185] F. Kern, K.S. Rogge, Harnessing theories of the policy process for analysing the politics of sustainability transitions: a critical survey, Environ. Innov. Soc. Trans. 27 (2018) 102–117.
[186] J. Schot, L. Kanger, Deep transitions: emergence, acceleration, stabilization and directionality, Res. Policy 47 (6) (2018) 1045–1059.
[187] J. Schot, W.E. Steinmueller, Three frames for innovation policy: R&D, systems of innovation, and transformative change, Res. Policy 47 (2018) 1554–1567.

David J. Hess is the James Thornton Fant Chair in Sustainability Studies and Professor of Sociology at Vanderbilt University, where he is also the Associate Director of the Vanderbilt Institute for Energy and Environment and the Director of the Program in Environmental and Sustainability Studies (www.davidjhess.net).

Benjamin K. Sovacool is Professor of Energy Policy at the Science Policy Research Unit (SPRU) at the University of Sussex Business School in the United Kingdom. There he serves as Director of the Sussex Energy Group (http://www.sussex.ac.uk/spru/research/themes/sussexenergygroup).